ISCA Webinar

SOUVENIR

International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security

16th - 19th March 2021

Organized by

Indian Society of Coastal Agricultural Research (ISCAR)
Canning Town, West Bengal, India

Collaboration with

ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

ACIAR

भाकृअनुप
ICAR

NABARD

NATIONAL JUTE BOARD

ISCA Webinar

SOUVENIR

International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security

16th - 19th March 2021

Organized by

Indian Society of Coastal Agricultural Research (ISCAR)
Canning Town, West Bengal, India

In
Collaboration with

ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India

Edited and compiled by:

Uttam Kumar Mandal,Tashi Dorjee Lama, D. Burman, Subhasis Mandal and Shisir Raut

Citation:

Mandal, U. K., Lama,T.D., Burman, D., Mandal, S. and Raut, S. (Eds.). 2021. Souvenir, International Symposium on Coastal Agriculture: Transforming Coastal Zone for Sustainable Food and Income Security, 16 - 19 March, 2021. Indian Society of Coastal Agricultural Research, ICAR-Central Soil Salinity Research Institute, Regional Research Station, Canning Town - 743 329, West Bengal, India.105 p.

March 2021

Published by:

The Honorary Secretary
Indian Society of Coastal Agricultural Research, ICAR-Central Soil Salinity Research Institute,
Regional Research Station, Canning Town – 743 329, West Bengal, India.

Cover Designed and Printed at:

Florence Offset Process Pvt. Ltd.
6A, S. N. Banerjee Road, Kolkata - 700 013
Email: florenceoffset@gmail.com
Tel: 033-2265 0018/2217 8117

©2021 Indian Society of Coastal Agricultural Research (ISCAR)

The views expressed in this publication are those of the author(s) and do not necessarily reflect the views of the editors and publisher.

भारतीय कृषि अनुसंधान परिषद
कक्ष क्र. 101, कृषि अनुसंधान भवन–II, पूसा, नई दिल्ली – 110 012, भारत
Indian Council of Agricultural Research
Room No. 101, Krishi Anusandhan Bhavan-II, Pusa, New Delhi - 110 012, INDIA

डॉ. सुरेश कुमार चौधरी / Dr. Suresh Kumar Chaudhari
उप महानिदेशक (प्राकृतिक संसाधन प्रबंधन)
Deputy Director General (Natural Resource Management)

Message

About 50-70 % of the global population live within 100 km of the coastline covering only about 4 % of earth's land. The entire coastal ecosystem is highly fragile and vulnerable to climate change, and highly endangered by the sea level rise following global warming. Agriculture is the major occupation of the people in the rural areas of coastal regions of the country but it is highly complex, risk prone, and entirely dependent on the vagaries of nature. The dwindling forest areas and their impacts on the environment & ecology in these ecosystems have a tremendous impact on the surrounding neighboring areas as well. The problems of livelihood in these areas, covering farm and non-farm sectors, are compounded manifolds owing to a series of technological, administrative and socio-economic constraints, typical of the ecosystems, and need to be addressed on a common platform.

I am delighted to hear that the Indian Society of Coastal Agricultural Research (ISCAR), Canning Town, West Bengal, India, in collaboration with ICAR-Central Soil Salinity Research Institute, Karnal, India is organizing an International Symposium on Coastal Agriculture (ISCA Webinar): **Transforming Coastal Zone for Sustainable Food and Income Security** during March 16 - 19, 2021 in a virtual mode.

I sincerely hope that the International Symposium shall identify the knowledge gaps and formulate the strategies to combat the challenges of the coastal ecosystems.

I wish the International Symposium a grand success.

(Suresh Kumar Chaudhari)

Phone : +91-11-2584 8364
Fax : +91-11-2584 8366
E-mail : ddg.nrm@icar.gov.in
Website : www.icar.org.in

Acknowledgements

The Indian Society of Coastal Agricultural Research (ISCAR) is grateful to Indian Council of AgriculturalResearch (ICAR), New Delhi, Australian Centre for International Agricultural Research (ACIAR), Australia and National Jute Board, Government of India for sponsoring this International Symposium. Generous financial support received from them is gratefully acknowledged.

The financial assistance received from the Research and Development Fund of National Bank for Agriculture and Rural Development (NABARD) towards the printing of proceedings of the seminar is gratefully acknowledged.

The society would also like to put on record the painstaking efforts taken by the staff of ICAR-Central Soil Salinity Research Institute, Karnal, Haryana, India and its Regional Research Station, Canning Town, West Bengal, India in organizing the event successfully.

Organizers

CONTENTS

Crop Species Distribution in Coastal India: Special Emphasis on Rice-based Cropping System

K. K. MANOHARA* and V. PARAMESHA

ICAR-Central Coastal Agricultural Research Institute, Ella, Old Goa-403402, Goa, India

Corresponding author: E-mail: manohar.gpb@gmail.com

The coastal stretch of India extends from Gujarat on the west coast to West Bengal on the east coast. The western coast of India is located between Kerala and Gujarat states and extends from the Arabian Sea to the Western Ghats. Its total length is 1400 km, the elevation ranges from 150 m to 300 m above sea level. It is characterized by sandy beaches, mud-flats, sand-dunes, alluvial tracts, estuaries, lagoons, residual hills, and more. The west coast can be divided into three parts: *Konkan:* It is the Northern part of the coast that includes Goa and Mumbai and extends from Daman to Goa. *Canara:* It is the central stretch of the coast that comprises three coastal districts: Dakshina Kannada, and Udupi district (South Canara), and Uttara Kannada (North Canara). *Malabar Coast:* It is the southern stretch, a long and narrow coastline that extends from the South of Goa to Kanyakumari. The eastern coast of India is located along the east coast of India. It is washed by the Bay of Bengal and extends from the Ganga delta to Kanyakumari (North to South). Its width ranges from 80 to 100 km that makes it more extensive and broad than its western counterpart. It is an aggradational plain which means an increase in the land elevation. It is characterized by sea beaches and lagoons. It is a sandy coast with straight shorelines and mostly comprises recent and tertiary alluvium deposits. It has received many large river-deltas made by the large rivers and receives rainfall from the North-East Monsoons. Although the cyclonic storms are frequent on this coast, it is suitable for the cultivation of both agricultural and horticultural crops. The eastern coast cuts through the three Indian states: Tamil Nadu, Andhra Pradesh, and Odisha. So, it also has some regional names like Utkal Coast in the Odisha and Coromandel Coast or PayanGhat in the Tamil Nadu.

With the higher rainfall and feeding habit of the people, rice occupies the prime place with respect to area and production in coastal parts of the country. The other cereal crops like maize, bajra, jowar and ragi are grown in patches in some of the coastal districts of the country. The pulse and oilseed crops such as moong, urad, cowpea, horse gram, groundnut, sesamum, mustard, sunflower, and soybean are grown in rice fallows during the *Rabi* season in coastal districts of India (Table 1). Among cash crops, sugarcane, tobacco, and cotton cultivation are more prominent especially in states like Gujarat, Andhra Pradesh, and Tamilnadu. The major cropping pattern observed in east coast and west coast is rice-based cropping systems, cotton-based cropping systems, Pulse based cropping system, and Groundnut based cropping system are prevalent.

Table 1. *Major crops and cropping systems of Coastal districts in different West Coast and the East Coast States of India*

Coastal States	Major crops	Major Cropping system
Gujarat	Rice, Arhar, Jowar, Urad, Gram, Sugarcane, Cotton, Groundnut, Jowar, Soybean, Maize, Wheat, Guar, Castor, Sugarcane, Sesamum, Moong, Tobacco	Rice-Pulses, Rice-Oilseed, Cotton-wheat, Cotton-Gram Soybean-Wheat, Tobacco-Summer Pearl Millet
Maharashtra	Rice, Groundnut, Ragi, Moong, Cowpea, Arhar, Ragi, Gram	Rice-Pulses, Ragi-Gram, Pigeonpea-Millets
Goa	Rice, Sugarcane, Cowpea, Moong	Rice-Cowpea, Rice-Rice Rice-Moong, Rice-Groundnut,
Karnataka	Rice, Cowpea, Chilli, Moong, Urad, Maize, Sugarcane	Rice-Pulses, Rice-Groundnut, Maize-Groundnut
Kerala	Rice, Cowpea, Moong, Sugarcane	Rice-Pulses

Coastal States	Major crops	Major Cropping system
Tamilnadu	Rice, Bajra, Cotton, Groundnut, Maize, Jowar, Moong, Urad, Small millets, Sugarcane, Ragi, Arhar	Rice-Pulses, Rice-Groundnut, Cotton-Moong, Ragi-Urad, Pigeonpea-Ragi, Bajra-Jowar, Maize-Groundnut
Andhra Pradesh	Rice, Cotton, Chilli, Groundnut, Maize, Moong, Sugarcane, Urad, Tobacco, Jowar, Small millets, Arhar/Tur, Sunflower, Niger	Rice-Pulses, Maize-Groundnut, Cotton-Jowar, Sorghum-Groundnut/Pearl Millet/Cotton, Sorghum-Chickpea
Odisha	Rice, Groundnut, Moong, Urad, Sesamum, Rapeseed &Mustard	Rice-Pulses, Rice-Oilseeds
West Bengal	Rice, Jute, Khesari, Urad Rapeseed & Mustard, Groundnut, Sunflower, Wheat, Moong, Potato, Sesamum	Rice-Jute, Rice-Maize, Rice-Mustard, Rice-Wheat, Rice-Groundnut and Rice-pulses, Jute-Wheat, Jute-Rapeseed &Musatrd

Source: Hand Book of Agriculture (2019)

Cropping Intensity

Cropping intensity measures the degree of land use for cultivation in a particular year. The higher amount of rainfall, soil type, and irrigation facility encourages growing double or triple cropping thereby higher cropping intensity. The exploitation of rice fallows for the cultivation of vegetables, pulses, and tuber crops during *Rabi* and *Summer* is also leading to higher cropping intensity. Cropping intensity is an important indicator of agricultural sustainability in the context of ecological security. In the process of increasing agricultural production, more and more area is being brought under cultivation, and farmers are growing more than one crop in the same field using modern inputs. Intensive cropping has given rise to many problems such as soil infertility, waterlogging, and alkalinity and salinity of the soil. Cropping intensity may therefore be taken as one of the determinants of ecological security. The value of cropping intensity varied from 100.2% to 142.0% on the west coast of India with the highest being in the Kannur district of Kerala (Fig. 1). On the east coast of India, the cropping intensity varied from 110.7% to 215%, and the maximum values are recorded in the North 24 Parganas district of West Bengal. The cropping intensity is found higher on the east coast of India than the west coast of India. In the coastal districts of India as a whole, the mean cropping intensity was 128%, which is lesser than the national average of 144%. Careful consideration is taken into account to avoid the ill effect of crop intensification by the inclusion of pulse crops in the cropping system. Encouraging short-duration green manure crops in cereal-cereal cropping systems is advantageous to restore the soil fertility and to break the crop pest and disease cycles.

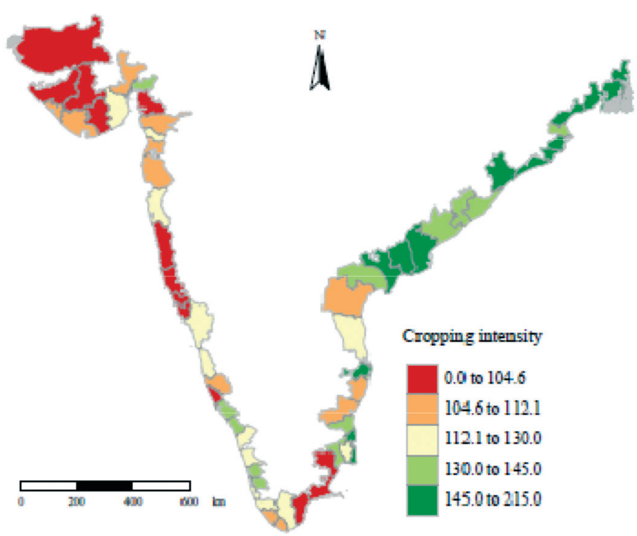

Fig. 1. Cropping intensity of Coastal India (Source: DES, 2014-15)

Rice scenario in the coastal states of India

Rice is the principal food crop in all the coastal states from Gujarat, Maharashtra, Goa, Karnataka, and Kerala on the west coast to West Bengal, Odisha, Andhra Pradesh, and Tamil Nadu on the east coast. Among the coastal states, West Bengal has the highest area of about 63.70 lakh ha followed by Andhra Pradesh, Odisha, Tamil Nadu, Maharashtra, Gujarat, Karnataka, Kerala, and least in Goa. The climatic conditions and agro-ecological system are completely different on the west coast compared to the east coast. The type of varieties preferred grain type requirement and the problem face are also different from each other.

These coastal states have sufficient area under coastal saline soils which often remain saline due to the ingression of brackish water into the paddy field during the high tide period. During peak monsoon, these fields are flooded with water sometimes complete submergence in the low lying areas thereby affecting the paddy crop. Rice cultivation starts with the onset of the South-West monsoon (May-June). The fields are protected by bunds. Normal cultivation practices like ploughing, laddering, and puddling the field by bullocks are done in West Bengal, Orissa, Andhra Pradesh, and Tamil Nadu. The seedlings are raised in a comparatively non-saline area as a dry or wet nursery according to convenience. After the field preparations and with sufficient water in the field, 40-50 days old seedlings are transplanted. In parts of Mysore, Maharashtra, and Gujarat the field preparation is done by spade and no ploughing is done (Bhattacharyya 1971). In these areas sprouted seeds are directly broadcasted instead of transplanting of young seedlings. In the transplanted condition the plants are spaced 15 cm or 25 cm apart, while in the broadcast condition they are about 15 cm apart. Harvesting starts from September and goes on up to November-December, according to the variety under cultivation. Long-duration varieties are preferred in West Bengal and Orissa, while short-duration varieties are in demand in Southern and Western Coastal states. The average productivity of rice varies from state to state in coastal region (Fig. 2).

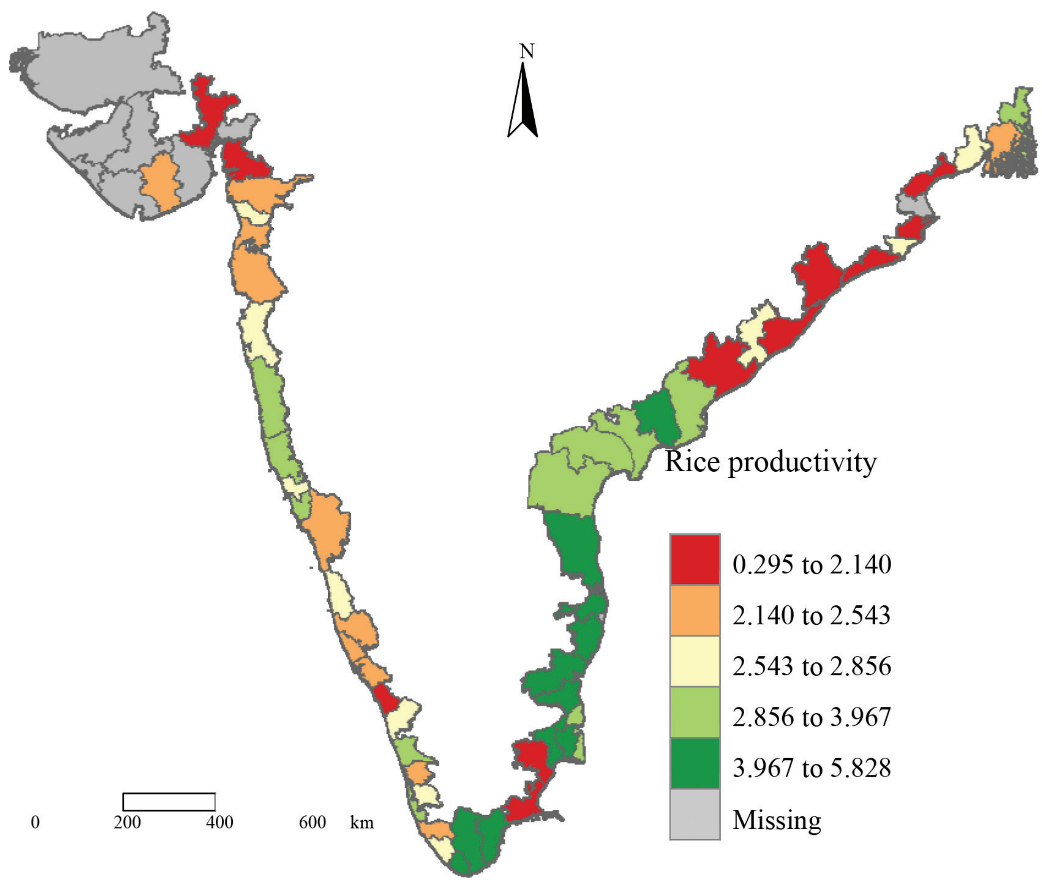

Fig. 2. Productivity (t ha^{-1}) of rice in the coastal districts of India

Distribution of rice on the Indian west coast

Kerala is India's southernmost state has a coastline of about 580 km stretching from Kasargod (North Kerala) to Thiruvananthapuram in South Kerala. Rice is the staple food of the state and is grown on different ecologies ranging from places situated below mean sea level (1.2 to 3 meters) in Kuttanad to high altitude (1400 meters) in Wayanad. The state has about 26,400 ha of coastal saline soils which are highly acid in reaction (Leena Kumari, 2011). There are unique rice farming systems like Pokkali, Kole, Kaipad being practiced by the farmers in the salt-affected coastal saline soils. Pokkali and Kaipadare the two important saline-prone natural organic rice production tracts of South and North Kerala, respectively.

The Karnataka state has about 0.21 Mha of rice area is covered in the coastal districts *viz.*, Udupi, Mangalore and Uttara Kannada of Karnataka. The average rainfall of the three coastal districts is about 3600 mm. The soils are mostly lateritic with poor fertility. Most of the area of rice is cultivated during the Kharif season. Rabi and Summer crop is also taken up in some places with assured irrigation facilities. Medium duration (135-140 days) varieties with coarse grains are preferred by the farmers (Rajanna, 2010). Popular rice varieties cultivated are Jaya, Jyothi, Shakthi, Phalguna, and others. Several landraces of rice are being cultivated in the coastal belt especially in the Uttara Kannada district. Farmers prefer both red and white kernel rice varieties having coarse grains. The major constraints in the region are poor fertility of the soil, soil salinity in the coastal saline regions, deficiency of major nutrients due to leaching, erratic rainfall, pest, and diseases. Coastal saline soils are having multiple stress problems like salinity, submergence, and water stagnation along with diseases like Bacterial leaf blight and blast. The average productivity of rice in the three coastal districts is 2.9 t ha. The productivity is very low (1.0-1.5 t ha^{-1}) in areas that are affected by salinity problems.

Rice is the predominant staple food crop of Goa grown on a 47,000 ha area of land in the State (Manohara and Singh, 2013). It is cultivated under three distinct ecologies *viz.*, rainfed shallow lowland (locally called *Kher* land), rainfed upland (*Morod*), and salt-affected low lying areas (*Khazan*). Among the different rice ecologies of the State, rainfed shallow lowland constitutes the major rice ecosystem with nearly 27,000 ha area followed by coastal saline soils with 12,000 ha area (Manohara and Singh, 2015) and upland rice ecology with 5,000 ha area. The major problem concerning rice production in the state are i) heavy rain during the *Kharif* season which leads to submergence like situation especially in the low lying area and in medium land ii) use of old varieties which are released many years back which inturn affecting in realizing the highest yield iii) biotic stress like insects and diseases. The major insect pests like leaf folder, stem borer, brown plant hopper and diseases like bacterial leaf blight, sheath blight, blast and false smut iv) among the abiotic stresses, salinity is a major problem in the low lying salt-affected areas, which results in a very poor crop of rice (Korikanthimath *et al.*, 2011). Efforts of the institute in developing salinity tolerant rice varieties has resulted in the development of four salt-tolerant rice varieties *viz.*, Goa Dhan 1 (KS 12), Goa Dhan 2 (KS 17), Goa Dhan 3 (GRS 1), and Goa Dhan 4 (JK 228) which can give almost double the yield compared to the existing local traditional salt-tolerant varieties. The yield of these varieties is about 3.0 tha^{-1} under moderate to high salinity conditions which can help in realizing better yield under salt-affected conditions.

Rice is the second most important food crop in Maharashtra followed by Jowar. The total area under rice is about 15.0 lakh hectare with average productivity of 2.01 tha^{-1}. Konkan region of Maharashtra comprising of four districts viz., Thane, Raigad, Ratnagiri, and Sindhdurg contributing more to the total rice production (42.91%) in the state (Thaware et al., 2014). The maximum rice area is under medium (rainfed shallow low land) with the little area in upland and about 60,000 ha under coastal saline soils. The high-yielding varieties and Sahyadri hybrid series contributed more to the increased productivity in the medium land and in irrigated situations. In coastal saline soils, the yield level is very low due to salinity, water stagnation, and submergence.

Rice occupies about 10.61% of the gross cropped area of the Gujarat State and accounts for around 25.5 % of the total food grain production. It is grown on an average of about 7.5 to 8.5 lakh hectares of land. Most of the rice area is under transplanted low land condition (60 to 70%) and about 40 to 45% is under rainfed transplanted and drill sown upland condition. The total production of rice in the state is about 15.84 lakh tonnes with a productivity of 2138 kg ha^{-1} (Pathak *et al.*, 2011). The productivity of irrigated rice is nearly 2.5 tons ha^{-1} whereas that of unirrigated rice is nearly 1.2 tons ha^{-1}. The major rice-growing ecologies are i) Irrigated Transplanted (60-70%) ii) Rainfed Transplanted (20-25%) iii) Rainfed upland drilled (12-16%) iv) Coastal/Salt affected transplanted rice (2-4%).

Distribution of rice in the Indian east coast

In Tamil Nadu, 0.68 million ha of area is covered by 13 coastal districts *viz*. Thiruvallur, Chennai, Kancheepuram, Villupuram, Cuddalore, Nagapattinam, Thiruvarur, Thanjavur, Pudukkottai, Ramanathapuram, Thoothukudi, Tirunelveli and Kanniyakumari. Zn deficiency is the major problem in the coastal region because of salinity. The average rainfall of the state is 925 mm. High-yielding varieties such as Savitri, Ponni, Swarnadhan, Mansarovar, Salivahan, and Pavizham were found suitable for shallow water salinity conditions. PVR 1, IET 1444 (Rasi), CO 43, ASD 16, TRY 1 and AU 1 are the varieties released in Tamil Nadu to combat saline/alkaline stress (Thiyagarajan and Kalaiyarasi, 2011).

The total area under rice cultivation in Andhra Pradesh is 43.87 lakh ha out of which 12.6% of the area is covered by nine coastal districts viz., Nellore, Prakasam, Guntur, Krishna, West Godavari, East Godavari, Vishakhapatnam, Vizianagaram, and Srikakulam (Cheralu, 2008). The coastal area has less fertile coastal sand with 3% entisol. Average rainfall range from 1000-1100 mm. Rice is cultivated in two seasons *viz.*, Saarva (*Kharif*) i.e. from June – November, and Dalva (*Rabi* season) i.e. from November – March In Rabi season cultivation depends on the availability of proper irrigation facilities. Popular rice varieties cultivated are Srikakulam, Sannual, Swarna, Vasundhara, Sonamahsuri, MTU-1001, MTU-1010, and IR-64. Farmers prefer varieties with medium slender grains with aroma and good cooking quality. Important abiotic factors reducing the rice crop yields are drought, waterlogging, temperature, cold, zinc deficiency, salinity etc. yield loss because of salt-affected soil is estimated to be 40-50 percent and loss of yield due to frequent cyclones and floods are highly common at the time of harvest. Major pests affecting rice in the coastal area are Brown planthopper (*Nilaparvata lugens*), Gallmidge (*Orseola oryzae*), and Panicle mite (*Staenotarsonemus spinki*). The average productivity in Andhra Pradesh is 3.43 t ha^{-1}.

The coastal belt of Orissa has 1.70 million hectares of rice land covered by coastal districts *viz.*, Ganjam, Khordha, Puri, Jagatsinghpur, Kendrapara, Bhadrak and Baleshwar. The average rainfall is recorded to be in the range of 1340 mm to 1460 mm in the coastal area. Coastal lands are characterized by low-lying topography, inadequate drainage, a fairly high water table of poor quality water due to higher salinity, and moderate to heavy soil texture. Soils are both coastal and deltaic alluvial. Coastal alluvial soil shows a high content of soluble salt mainly Sodium Chloride because of tidal inundation. Tall rice varieties like Patnai 23, SR 26B and Lunishree are grown during *Kharif* season (Das 2012). Major damage to the rice yield is because of pests such as brown planthopper, white-backed planthopper, stem borer, and gall midge also sheath-rot and bacterial leaf blight are major diseases observed to affect the rice yield. The total rice production in this region is estimated to be 2.68 million tonnes with a productivity level of 1577 kg ha^{-1}. Yield is very low (500-700 kg ha^{-1}) in the salt-affected area as the crop is highly sensitive to salinity at the early stage of growth.

The coastal area of approximately 14.6 lakh ha of West Bengal is covered by four districts *viz.*, North 24-Parganas, South 24-Parganas, Howrah, and Purba Midnapore. The overall climatic condition of the area is tropical humid with rainfall between 1600-1800 mm. The coastal saline soils are often affected with deficiency of ferrous and zinc which causes chlorosis and reduced tillering. Rice is grown in about 10 lakh hectare areas during the different seasons in coastal lands. Farmers also follow the Rice-Fish farming system in the coastal region where fields have sufficient water holding capacity. Nonabokra, Matla, Hamilton, Ghetu and Patnai 23 are few salinity tolerance rice varieties that are preferred in coastal saline soils whereas Mohan, Lunishree, Jarava, MTU 7029, CR 1001, and CR 1009 are few popular varieties grown in the coastal belt of West Bengal (Adhikari *et al,*. 2011). Farmers prefer varieties with good head rice recovery, eating quality, expansion during cooking, resistance against temporary submergence. Rice grown in area adjacent to rivers carrying seawater from the Bay of Bengal faces tidal pressure because of which it gets affected during the reproductive stage causing poor exertion of the panicle. Sheath blight, blast, brown spot, bacterial blight, and rice tungro are major diseases affecting rice productivity. The state average of rice productivity was 2573 kgha^{-1}. The yield of rice in coastal saline soil during *Kharif* is 3 tonsha^{-1} and in Rabi is about 4 tonha^{-1}.

Pulses

India is the largest producer as well as the consumer of pulses in the world. These are the major source of protein in a vegetarian diet. Major pulses that are grown in coastal India are tur (arhar), urad, moong, and gram. Pulses need less moisture and survive even in dry conditions. Being leguminous crops, all these crops help in restoring soil fertility by fixing atmospheric nitrogen. Therefore, these are mostly grown in rotation with other crops. The major area is seen under rice fallows in both west coast and east coast. Pulses crops are having potential to grow under residual soil moisture condition after rice, maize and cotton harvest in both the coasts. Rice-pulse cropping system is one of the predominant cropping system observed in Goa, Maharshtra, Tamilnadu and Andhra Pradesh. In Gujarat, Tamilnadu and in Andhra arhar is grown in *Kharif* season also. There is a huge potential to intensify the area under pulse production by growing as intercrop or as border crop in *Kharif* season wherever maize and cotton were the main crop. Providing life saving irrigation during *Rabi* under residual moisture condition will boost the pulse production. Under rice fallows, moong is grown as sequential crop under residual moisture conditions in Maharashtra, Karnataka, Orissa, West Bengal, Gujarat, Tamil Nadu and Andhra Pradesh. The maximum area is found in Thiruvarur districts of Tamil Nadu (52575 ha) and maximum production is noted in Guntur districts of Andhra Pradesh (61251 tons). The productivity ranged from 0.19 to 1.28 tons ha^{-1} in Thootukudi districts of Tamil Nadu and Guntur districts of Andhra Pradesh, respectively (Fig. 3). The arhar is grown both as *Kharif* and *Rabi*

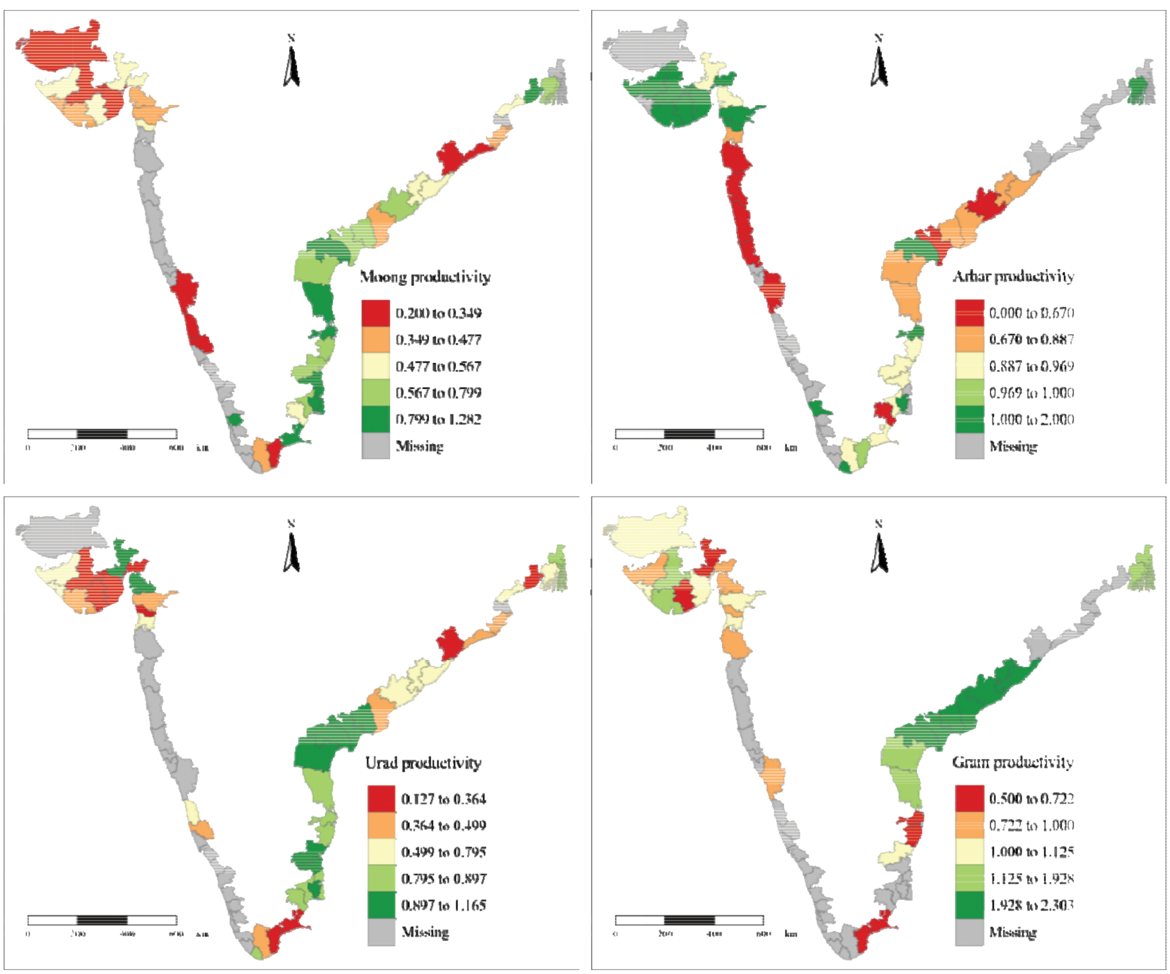

Fig. 3. Productivity (tha^{-1}) of major pulse crops in the coastal districts of India

crop in coastal districts of the country. In states like Gujarat, Tamil Nadu and Andhra Pradesh the crop is grown in *Kharif* season. The maximum area and production of Arhar is found in 64100 ha and 80800 tons in Vadodar districts of Gujarat. The productivity of Arhar is higher (2 ton ha^{-1}) in Bhavanagar districts of Gujarat. The cultivation of urad is mainly concentrated in coastal districts of Gujarat, Tamil Nadu, Andhra Pradesh, Orissa and West Bengal. The maximum area, production and productivity of urad (125694 ha, 146478 tons and 1.16 tons ha^{-1}) is seen in Krishna districts of Andhra Pradesh. One of the most important *Rabi* pulse of the country, occupying highest pulse area. Among different coastal states the cultivation of gram is more prominent in Gujarat and Andhra Pradesh. The maximum area and production are recorded in Prakasam districts of Andhra Pradesh (50750 ha and 95867 tons) and the highest productivity (2.3 tons ha^{-1}) was noticed in Guntur district of Andhra Pradesh.

Oilseeds

India is the largest producer of oilseeds in the world. Different oil seeds are grown covering approximately 12 per cent of the total cropped area of the country. Main oilseeds produced in coastal India are groundnut, mustard, sesamum, soybean, castor seeds, and sunflower. Most of these are edible and used as cooking mediums. However, some of these are also used as raw materials in the production of soap, cosmetics, and ointments. Groundnut is a both Kharif crop and Rabi crop under rice fallow and accounts for about half of the major oilseeds produced on the west coast and east coast. Andhra Pradesh, Tamilnadu, Karnataka, Gujarat, and Maharashtra are the major producer of groundnut. Groundnut, Mustard, and Sesamum are Rabi crops grown after rice, maize, and sorghum on the east coast. Castor seed is grown both as Rabi and Kharif crop as a sole crop. Oilseed cultivation can be intensified by grown these crops as intercrop/border crops in coconut and areca nut plantations of Kerala, Goa, and Coastal Karnataka. As they require less water and enrich the soil fertility best suited for sequential cropping under water shortage conditions. Groundnut is a very feasible crop to grown as a sequential crop after rice under residual moisture conditions and known as a soil restoring crop because of its higher nitrogen fixation ability. The cultivation of groundnut is seen in all the coastal states except Kerala. The maximum area under groundnut cultivation (317200 ha) is in the Rajkot districts of Gujarat. The maximum production of 158600 tons is recorded in the Junagadh districts of Gujarat. However, the highest productivity of 5.22 tons ha^{-1} in Thiruvarur districts of Tamil Nadu (Fig. 4). The sesamum is one of the most important oilseed crops of the country. Maharashtra, Andhra Pradesh, and West Bengal are having major areas among coastal states. The area under sesamum cultivation is found maximum in Kutch districts of Gujarat and the maximum production is in Junagadh districts of Gujarat. However, the highest productivity of 31.9 tons ha^{-1} is recorded in the Bharuch districts of Gujarat. The area under sunflower is increasing over the year due to its short duration and more adaptability. The cultivation of sunflower is more prominent in the coastal districts of West Bengal, Andhra Pradesh, and Tamil Nadu. Among different coastal districts, the highest area and production was noticed in the Prakasam district of Andhra Pradesh (8186 ha and 7826 tons). Whereas the maximum productivity of 1.78 ton/ha is noticed in the Midnapore district of West Bengal. Castor is one of the important non-edible oilseed crops of the country. Among coastal states, Gujarat occupies the prime place with respect to area and production compared to other states. The maximum area and production of castor was noticed in Kutch district of Gujarat (129100 ha and 244500 tons, respectively); whereas the crop productivity of 2.29 tons ha^{-1} is observed in Vadodara district of Gujarat.

Sugarcane

Sugarcane (*Saccharum officinarum*) is a widely grown crop in India. It employs over a million people directly or indirectly besides contributing significantly to the national exchequer. It is a long-duration crop and requires 10 to 15 and even 18 months to mature, depending upon the geographical conditions. It requires a hot and humid climate with an average temperature of 21°-27°C and 75-150 cm rainfall. It can grow on a variety of soils including loams, clayey loams, black cotton soils, brown or reddish loams, and even laterites. Sugarcane can tolerate any kind of soil that can retain moisture. However, deep rich loamy soils are ideal for its growth. Sugarcane exhausts the fertility of the soil quickly and extensively and its cultivation requires a heavy dose of manures and fertilizers. After rice, sugarcane cultivation is more prominent in the coastal districts of the country. The water availability and

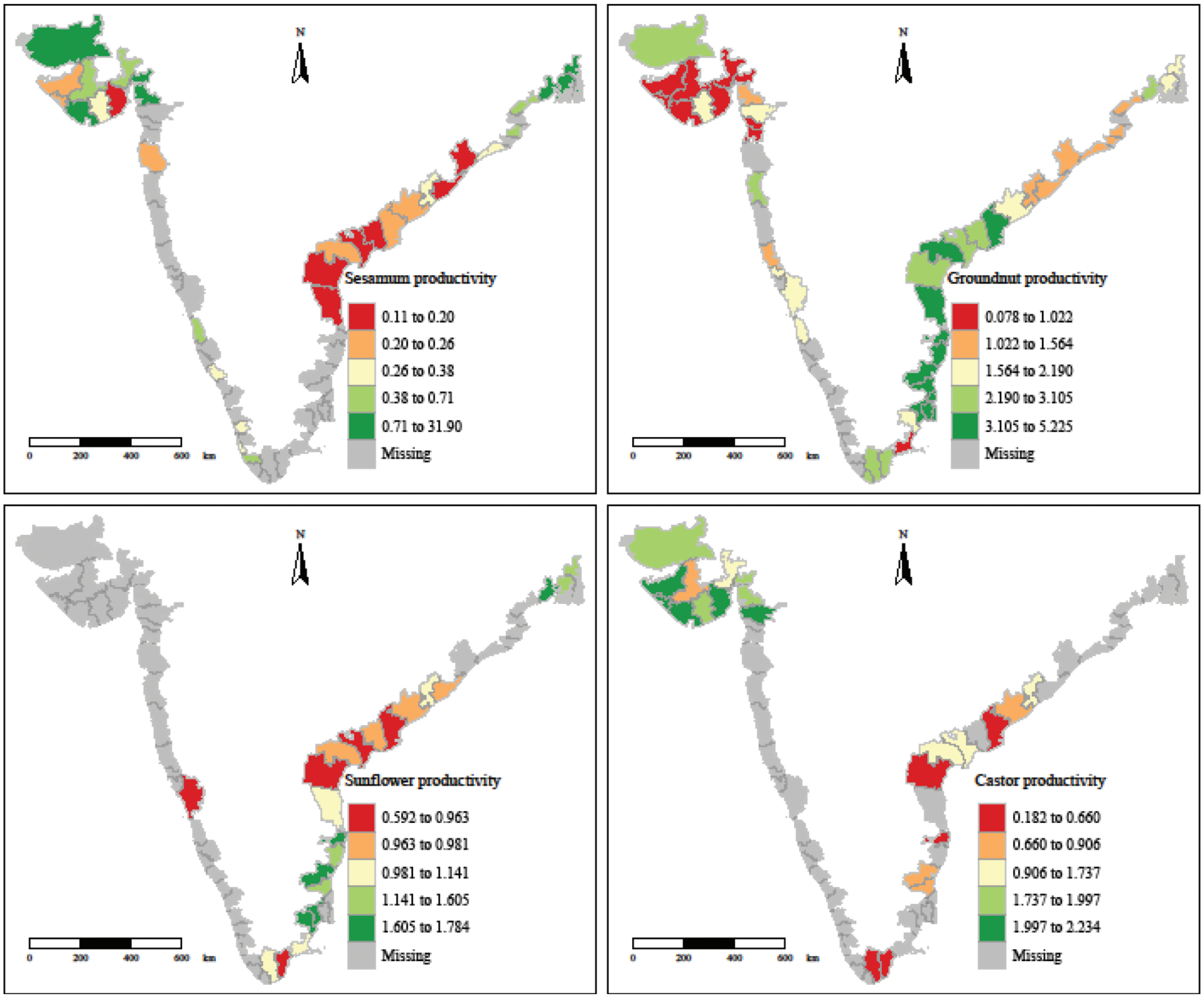

Fig. 4. Productivity (t ha^{-1}) of major oilseed crops in the coastal districts of India

congenial weather conditions favoring sugarcane cultivation in the coastal region of the country. Intensive sugarcane cultivation is practiced in Tamil Nadu, Andhra Pradesh, and Gujarat and in some patches of West Bengal, Karnataka, Kerala, Orissa, and Goa which comes under the tropical Sugarcane region. The maximum area, production, and productivity of sugarcane are noticed in the Vilupuram districts of Tamil Nadu (88786 ha, 10598908 tons, and 119.4 tons ha^{-1}) (Fig. 5). Under the east coast, the productivity per unit area is more compared to the west coast districts of the country. The lowest yield is observed in Goa state. Adoption of an improved package of practice and improved varieties will enhance crop yield on the west coast of India. The poor weed and nutrient management in the *Kharif* season is contributing to lower yield on the west coast of India.

Constraints

- Small and marginal land holdings
- Lack of standardised package of practices
- Poor soil fertility management and coastal land use planning
- Hill slopes limits the agriculture production
- Poor management of coastal saline lands and Marshy lands
- Poor management of water bodies
- Lack of awareness about Integrated Pest and nutrient Management

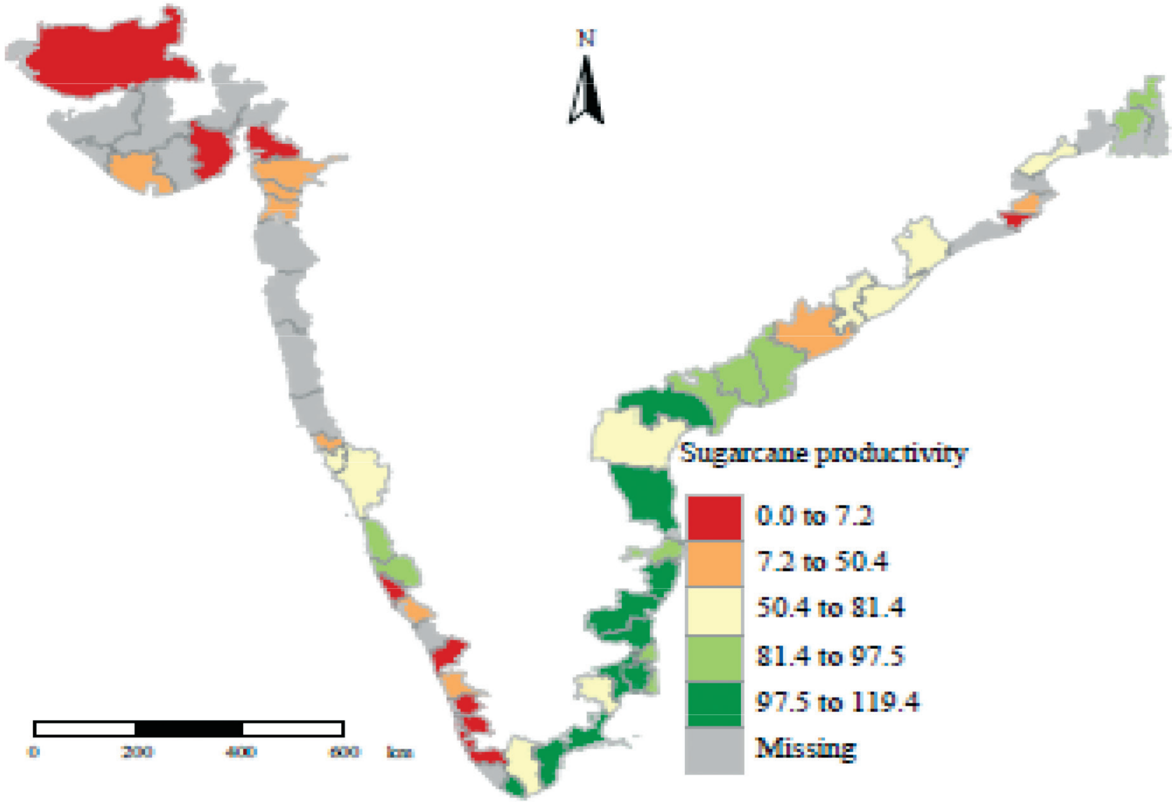

Fig. 5. Productivity (t ha^{-1}) of Sugarcane crop in the coastal districts of India

- Low soil pH, high erodibility, low soil fertility and predominance of light soils with low water retention capacity.
- Limited irrigation facilities; lack of assured irrigation as well as of systems and methods for higher water use efficiency.
- Lack of value addition/processing centres especially in rural areas.
- Inadequate / ineffective quality control mechanism for agriculture and allied sector inputs.
- Non-availability of critical inputs in time due to various reasons.
- Absence of certification for organic produce.
- Lack of seed production of HYV / calves within the state
- Better income and employment opportunities in Non –farm sectors
- Lack of awareness about the government schemes
- Poor marketing network and infrastructure
- Absence of extension mechanism at the village level
- High cost of agricultural labour
- Reluctance of youth towards agriculture
- Insufficient investment in the agriculture sector (other than tourism & mining)
- Low Seed Replacement Rate (SRR) for various crops and non-availability of quality planting material
- Lack of crop diversification horizontal as well as vertical Way forward
- Crop diversification with pulse and oilseed crops
- Brining more under Rabi crops cultivation
- Research and development in organic farming
- Investment on community soil and water conservation
- Bringing more area under irrigation by assisting for revitalization of existing ponds/tanks. Harvest rainwater more effectively

- Encouraging farm mechanization increase net returns and reduce dependency on costly and unreliable manual labour
- Encouraging the formation of User Groups/Self Help Groups etc, to reduce cost of production and realize better returns
- Use of quality seeds including hybrids, use of manures and fertilizers and bring more area under cultivation through inter/mixed cropping.
- Safeguard agricultural salt affected fields by repairs/remodeling of protective embankments and sluice gates to prevent inundation of salt water in fields.
- Standardization of production technologies for hybrid vegetable cultivation and production of high-value vegetables
- Provide better market linkages and utilization of market intelligence
- Promote agro-tourism.
- Skill development in rural youth and farm women's through capacity building programe

BIBLIOGRAPHY

Adhikari, B., Bag, M. K., Bhowmick, M. K. and Kundu, C. (2011). Status paper on rice in West Bengal.Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Bhattacharyya, R. K. (1971) Rice cultivation on saline soils. In Proceedings of Symposium "Science and India's food problem"

Cheralu C. (2008). Status paper on rice in Andhra Pradesh. Published at rice knowledge management portal (RKMP), Directorate of Rice Research, Rajendranagar, Hyderabad.

Das, S. R. (2012). Status paper on rice in Orissa. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

DES, Respective State Report (2014–2015). Directorate of Economics and Statistics, Ministry Of Agriculture, Cooperation and farmers welfare.

Hand Book of Agriculture. 2019. Indian Council of Agriculture, New Delhi 6th edition.

Korikanthmath, V. S., Manjunath, B. L. and Manohara K. K. (2011) Status paper on rice in Goa. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Leena Kumari, S. (2011). Status paper on rice in Kerala. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Manohara, K. K. and Singh, N. P. 2013. Genetic divergence among rice landraces of Goa. Oryza, **50**(2): 100-104.

Manohara, K. K. and Singh, N. P. 2015. Genetic variability, correlation and path analysis in rice (Oryza sativa L.) under coastal salinity conditions of Goa. Journal of the Indian Society of Coastal Agricultural Research. **33**(1): 34-39.

Pathak, A. R., Mehta, A. M. and Vashi, R. D. (2011). Status Paper on Rice in Gujarat. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Rajanna, M. P. (2010). Status paper on rice in Karnataka. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Thaware, B. L., Kunkerkar, R. L. and Shivade, H. A. (2014). Status paper on rice in Maharashtra.Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Thiyagarajan, K. and Kalaiyarasi, R. (2011). Status paper on rice in Tamil Nadu. Rice Knowledge Management Portal (RKMP), Directorate of Rice Research, Hyderabad.

Reclamation and Management of Salt-affected Soils for Crop Production with Special Emphasis on Coastal region: Trend and Prospects

D. K. SHARMA*

Former Director, ICAR-Central Soil Salinity Research Institute, Karnal-132001, India

**Corresponding author: Email: ds5550@gmail.com*

Global land and water resources are adversely affected by a range of physical and chemical degradation processes like soil erosion and compaction, drought, waterlogging and salinity (FAO and ITPS, 2015). As productive soils and waters are shrinking rapidly (FAO and ITPS, 2015), yield increases in major food staples (*e.g.*, rice, wheat and maize) remain far below the expected levels (Ray *et al.* 2013) and hunger and malnutrition remain pressing global priorities (Ramankutty *et al.* 2018), there is a growing attention on harnessing the marginally productive lands and waters for the global food and nutritional security (UNCCD, 2017). Arable lands in marginal areas suffer from various soil and climatic constraints that together diminish their productivity to varying extents, and in extreme cases, may render them completely unsuitable for agricultural production. Though land and water degradation are caused by both natural (*e.g.*, aridity, poor soil fertility) and anthropogenic (*e.g.*, crop intensification, over irrigation) factors, human activiies often accelerate the natural degradation processes to such an extent that restoration measures become absolutely essential for halting further degradation and improving the crop yields (Lewis and Kelly 2015). Marginally productive salt-affected soils (SAS) are widespread in arid and semi-arid tropics and occupy about 1000 million ha (M ha)land area globally (FAO and ITPS, 2015; Wicke *et al.* 2011). The North Western Asia, Northern Africa, Australia and South Asia are some the global regions that are more adversely hit by soil salinity and related problems. It may be a matter of relief, however, that a bulk of global salt-affected soils have only slight (65%) or moderate (20%) levels of salinity and sodicity (Wicke *et al.*, 2011), and thus manageable through soil, water and crop management practices.

Salt-affected soils refer to the presence of excess soluble salts/exchangeable sodium and the associated problems in crop lands. Unlike localized impacts in the past, the last few decades have seen an alarming increase in the salt-induced land and water degradation in several irrigated and rainfed areas across the world. Like other kinds of degraded lands, salt-affected soils are formed either naturally over a geological timescale (*i.e.*, primary salinity) or by anthropogenic factors (*i.e.*, secondary salinity). Irrigation mismanagement and the clearing of perennial vegetation are the principal drivers of secondary salinity development in irrigated and dryland areas, respectively. In comparison to naturally formed salt-affected soils, secondary salinity affected lands are relatively difficult to manage due to presence of a shallow (often saline) water table $\leq$ 2.0 m below the surface. The area under salt-affected soils in India is about 6.73 M ha. The states of Gujarat (2.23 M ha) followed by Uttar Pradesh (1.37 M ha), Maharashtra (0.61 M ha), West Bengal (0.44M ha) and Rajasthan (0.38 M ha) have the maximum area and together account for almost 75% area under SAS in country. In addition, about 25% of the underground waters are either saline or sodic with some states like Rajasthan, where about 80% of the groundwater is of poor quality, greatly suffering from the salinity problem (Singh, 2009). According to estimates, salt-affected area in country is likely to increase to 16.2 M ha by 2050. The problem of poor quality waters would also significantly increase in the near future due to planned expansion in irrigated area and intensive use of natural resources to the diverse livelihood requirements of a burgeoning human population.

In this paper, an overview of popular salinity management technologies is presented. Several potential interventions under different stages of development are also highlighted. The factors stalling the reclamation of salt-affected soils are discussed and the future research directions proposed.

RECLAMATION AND MANAGEMENT PRACTICES

Gypsum and other amendments

Factors like relatively low cost, easy availability, ease in application and better efficiency compared to other amendments have made gypsum ($CaSO_4.2H_2O$) one of the widely used ameliorants for sodic soils. In India, gypsum application @ 50% gypsum requirement (GR) was suggested for the conventional tall varieties of rice and wheat. Widespread adoption of gypsum-based technology has led to the reclamation of about 2.17 M ha sodicity-affected area in India, contributing nearly 16 million tonnes year^{-1} of rice and wheat to the national pool and providing employment to 155 million farm workers year^{-1}. Estimated expenditure on gypsum technology (Rs. 76,000 ha^{-1}), including gypsum (57%), farm development (27%) and labour (16%) costs, can be further reduced by the conjunctive use of gypsum and salt tolerant varieties (Sharma *et al.* 2016b). Gypsum has also been widely used to neutralize the residual sodium carbonate (RSC) in irrigation waters through a technique popularly called the 'gypsum-bed technology'. Water flowing through gypsum-beds picks Ca^{2+} (3-5 meq L-1) and thus becomes quite safe than original Na^+ laden water (Tyagi, 2003). However, dwindling availability, poor quality and rising prices of gypsum have increased the interest in other alternative amendments for sodic soil reclamation. Alternative amendments are organic or inorganic compounds that improve the physico-chemical and biological properties of the salt-affected soils. Farm yard manure (FYM) application improved the physico-chemical properties and crop yields in calcareous sodic soils irrigated with high RSC water (10-12.5 m mol L^{-1}) by solubilising the precipitated $CaCO_3$ (Choudhary *et al.* 2011). While soil pH, ESP and electrical conductivity decreased, infiltration rate improved in a FYM treated (25 t ha^{-1}) sodic soil (pH= 9.3) (Makoi and Ndakidemi, 2007). Application of municipal solid waste compost (MSWC) increased the dissolution of precipitated $CaCO_3$ leading to higher availability of soluble Ca_2+ and the displacement of Na+ ions from the soil exchange complex. Decrease in soil pH and increase in N and P availability were more pronounced when MSWC (10 t ha^{-1}) and gypsum (GR25) were applied together compared to gypsum (GR50) application alone (Sundha *et al.* 2017). MSWC treated saline-sodic soils (ECe: 7.2 dS m^{-1} and pH: 8.4) under mustard-pearl millet sequence exhibited higher activities of enzymes dehydrogenase, alkaline phosphatise and urease, more microbial biomass carbon and nutrient availability than control plots (Meena *et al.* 2016). Promising results of these investigations have led to more concerted focus on promoting MSWC as a commercial alternative amendment. Recently, an experiment has been initiated to assess the feasibility of 'Reliance Formulate Sulphur' as a sodic soil reclaimant. Similarly, practical utility of marine gypsum as a substitute to mined gypsum is also being investigated. Marine gypsum, a by-product of common salt (NaCl) manufacturing, contains NaCl, $MgCl_2$ and $MgSO_4$ as impurities that may increase the ionic strength of aqueous solution by decreasing its activity coefficient resulting in increased solubility of gypsum and higher reclamation efficiency compared to the mineral gypsum (ICAR-CSSRI, 2017a).

Sub-surface drainage

The efficiency of sub-surface drainage (SSD) in reclaiming waterlogged saline lands has been successfully demonstrated in Haryana, Punjab, Rajasthan, Gujarat, Maharashtra and Karnataka states. Both public and private investments in SSD projects have led to the revival of nearly 70,000 ha area in different agro-ecological regions. Although reclaimed lands exhibit marked improvements in crop yields (45.0% in rice, 111% in wheat and 215% in cotton) and cropping intensity (>40.0%), slower spread of SSD technology implies that further improvements in design and drain spacing are essential to increase its acceptability among the farmers. Specifically, the current estimated expenditure on SSD installation (INR 65,000 ha^{-1} for government-funded schemes in the alluvial soil areas of Haryana and INR 1,25,000 ha^{-1} for the heavy textured Vertisols of peninsular India) (Sharma *et al.* 2016a) needs to be cut down so that even small landowners could invest in the individual projects. Another constraint stalling the spread of SSD technology is the lack of full reclamative pumping at various project sites. As further reductions in government subsidies on diesel would only inflate the operational costs, cheaper and environment-friendly solutions (*e.g.*, solar powered pumping) are needed to upscale the SSD adoption. In Sangali district of Maharashtra, where SSD is operational over 1000 ha waterlogged saline area covering about 1300 farmers, reductions in water table and salinity led to the doubling of sugarcane, wheat and soybean yields. Similar results were seen in the Belgaum District of Karnataka state where SSD installation (≈925 ha area) increased the cropping intensity from around 60% (pre-SSD) to 78% (post-SSD); due apparently to considerable reduction in soil salinity (ICAR-CSSRI, 2017a). In addition to higher installation and operational costs, lack of co-operative management and the problems encountered in the safe disposal of saline effluent are other hurdles to the success of SSD technology. Virtual non-existence of water users' associations for the drainage projects in many parts of India calls for appropriate institutional arrangements to boost the farmers' confidence and participation. Difficulties in the safe disposal of saline effluents can partly be overcome by reusing saline drainage water for aquaculture, irrigation and soil reclamation.

Because localized disposal of salt and pollutant laden drainage effluents is often quite tedious in the landlocked areas, doable solutions have been worked out to utilize it on-site in an environment-friendly manner. There is evidence that saline drainage effluents could be harnessed for crop irrigation, particularly in areas where fresh water is available for pre-sowing irrigation and for blended use with saline water at the subsequent crop stages. Reuse of SSD effluents in irrigation could also reduce the area affected by shallow water tables. A long-term investigation at a SSD site revealed that grain yields of wheat, sorghum and pearl millet were not much affected up to EC_{iw} 12 dS m^{-1} (Sharma and Rao, 1998). Conjunctive use of fresh canal water and drainage effluent [EC_{iw}: 7.2-9.8 dS m^{-1}; SAR: 8.4-13.5 (m mol $L^{-1})^{1/2}$] was found to be viable in sunflower-sorghum rotation than continued use of saline water (Sharma *et al.* 2005). Even better results could be achieved by ensuring leaching of the salts accumulating during the winter season in effluent irrigated soils. Use of high yielding salt tolerant cultivars having low leaching requirement is recommended to further improving the acceptability of this practice. Saline aquaculture using the high value shrimp species adapted to seawater salinity (*e.g.*, tiger shrimp: *Penaeus monodon*) (Purushothaman *et al.*, 2014) as well as common inland fish species (CSSRI, 2013) could be high income generating options in the waterlogged saline areas of North-Western India. Similarly, commercial cultivation of high value seaweeds could be a profitable alternative to the existing land use systems in the poorly drained coastal saline lands (SubbaRao and Mantri, 2006).

Bio-drainage

In this method, salt tolerant trees having a high transpiration rate are raised to prevent irrigation-induced salinity in canal commands. Being a preventive approach, bio-drainage gives best results when tree plantings coincide with the initiation of irrigation projects. Some tree species found to be efficient bio-drainers are eucalyptus, poplar and bamboo. In contrast to the annuals, tree roots extend to the deeper soil depths (>2 m) making them efficient in removing the groundwater rapidly such that water table decreases by 1-2 m in a short span of 3-5 years (Devi *et al.* 2016). *Eucalyptus* trees have a high bio-drainage capacity removing about 5000 mm of water from the normal and moderately deep (~1.5 m) water tables. However, bio-drainage efficiency declines under both shallow (~1 m) and deep (~2 m) water table conditions and with increase in the salinity of groundwater. Nonetheless, Eucalyptus trees could transpire about 50% of the water compared to that under normal conditions at salinities as high as 12 dS m^{-1} (Chhabra and Thakur, 1998). Strip plantations of *Eucalyptus tereticornis* on ridges in north-south direction not only lowered the water table by 0.85 m in 3 years but also sequestered 15.5 t ha^{-1}carbon during the first rotation of 64 months.

Irrigation Management

Globally, irrigated agriculture consumes nearly three fourths of the total available water while the remaining is used by the industrial and municipal sectors. While population pressure and rapid urbanization continue to usurp large volumes of fresh water, climate change impacts (*e.g.*, glacial melt and drying of rivers) are expected to further reduce the fresh water availability, especially in arid and semi-arid regions where irrigated lands will increasingly have to rely on poor quality and waste waters. Micro-irrigation, particularly drip irrigation, offers advantages like reduction in irrigation volumes, weed control and fertigation compared to the common surface methods of irrigation. Furthermore, drip irrigation has been found to a viable technique in areas relying solely on saline/sodic waters. Nevertheless, regular application of saline water through drip could result in salt accumulation in the surface soil that can be prevented by switching over to sub-surface drip irrigation to push the salts to lower depths. Deficit irrigation is another potential technique in which irrigation water is applied below the crop evapo-transpiration (ET_c) requirement. Deficit irrigation seems to be particularly well suited to the fruit and vine crops in semi-arid and sub-humid regions receiving adequate rainfall to partly meet the crop water needs at the critical irrigation stages (Fereres and Soriano, 2007). In partial root-zone drying (PRD) method, only half of the root-system is wetted and the remaining half is kept dry. Alternate partial root-zone irrigation (APRI) and fixed partial root-zone irrigation

(FPRI) are the two variants of PRD technique. PRD has been found to curtail irrigation water use considerably in fruit crops like peach, olive and grapes (Sadras, 2009; Sepaskhah and Ahmadi, 2010).

Irrigation timing, depth and frequency in sodic soils vary from the normal soils, especially in moderately salt tolerant but waterlogging sensitive crops like wheat. Under such conditions, wheat crop should be irrigated at critical stages *viz.*, crown root initiation, tillering and milk stage for higher grain yields (Sharma *et al.* 1990). Similarly, single irrigation at rosette stage 30 days after sowing ensures higher relative growth rate and seed yield in mustard than when irrigation is done at the pod formation stage (Sharma and Singh, 1993). Proper irrigation scheduling and higher applications of nitrogenous fertilizers can permit sustained use of even highly sodic water (RSC up to 10 meq L^{-1}) in coarse textured soils of semi-arid areas having ≥500 annual rainfall (Sharma and Sharma, 1999).In addition to bio-drainage and conjunctive use of canal and low quality groundwater, multiple well points system is recommended to ensure skimming of freshwater floating over brackish groundwater in the waterlogging and sodicity affected areas of North-Western India (Gupta and Singh, 2014).

Land shaping models

Transient (seasonal) or permanent waterlogging often causes significant crop losses in nearly 2.5 M ha irrigated area in India (NRSA, 2014). Vast stretches of sodicity affected lands in the IGP are prone to the waterlogging in the post-monsoon season, which adversely affects winter season crops like wheat. Waterlogging problem has magnified over the years in sodic land areas irrigated by Sarda Sahayak Canal in Uttar Pradesh state, particularly in poorly drained soils also irrigated with sodic groundwater. Gypsum application does not give satisfactory results in such waterlogged sodic lands (water table <2.0 m). Furthermore, lack of natural gravity outlets is a hindrance to sub-surface drainage in such soils. In such situations, inverting the less sodic lower soil profiles upside down in a pre-specified soil column makes the surface soil congenial to crops by lowering the water table below a critical depth. Land modification (fish ponds and raised and sunken beds) based integrated farming models have been found to be a feasible solution to increase the productivity of waterlogged sodic soils (ICAR-CSSRI, 2017a). In sunken beds, water table lies at about 1 m depth and thus reduced upward salt movement. Rice, water chestnut and integrated rice-fish culture are the viable land use options for sunken beds. Vegetable crops could be grown on raised beds (Verma *et al.* 2015). Factors like heavy rainfall, relatively flat topography, poor water infiltration and lack of drainage arrest the downward flux of water in the coastal areas. Under such conditions, regular application of even marginally saline water (2 dS m^{-1}) leads to salinity development. In fine textured low lying coastal soils rich in insoluble humic acid, problems of poor sorptivity and permeability are particularly noticeable. Like waterlogged sodic soils of the IGP, lack of natural outlets and backwater flow make both surface and sub-surface drainage interventions less effective. Although deep ploughing, addition of sand and rice husk, ponding of fresh water and vertical drainage could improve the hydraulic conductivity of such coastal soils temporarily, their widespread adoption was hampered by one constraint or other. The *kharif* rice growing coastal soils of West Bengal state have a low cropping intensity and mostly remain fallow during the *rabi* season. Simple land modification techniques like farm pond and integrated paddy-fish model could be an easy means of land use intensification under such conditions. Rainwater stored in these structures ensures the availability of good quality irrigation water during the dry rabi season. Farm ponds are created by excavating ≈20% of the soil from a depth of ≈3 m. Rainwater stored in these ponds can be used for round-the-year irrigation of crops grown on embankments. Besides fish rearing in the pond and crop cultivation on dykes, poultry and duckery can also be taken up for enhancing profits while recycling the resources among different components. In paddy-cum-fish model, trenches (3 m top width × 1.5 m bottom width × 1.5 m depth) are made around the farmland. Excavated soil is used for making dykes (1.5 m top width × 1.5 m height × 3 m bottom width) to prevent free flow of water from the field and harvesting more rainwater in the field and trench. While dykes are used to grow vegetables throughout the year, rest of the farm area including trenches is used for integrated rice-fish culture (Mandal *et al.* 2013). These interventions can increase the cropping intensity from 114% to 186%. These techniques have been demonstrated at farmers' fields for increasing the farm incomes. Subsequent to the adoption of land shaping interventions, farmers' net income could increase from mere INR 470 $month^{-1}$ (*kharif* rice) to as high as INR 11999 $month^{-1}$ (rice-fish-vegetable cropping system). Betel vine cultivation has also emerged as an attractive option to further increase the farm incomes (Mandal *et al.* 2017).

Agro-forestry models

Many agro-forestry species, grown with or without soil amendments like gypsum, improve the physical, chemical and biological properties of sodic soils. For example, gypsum treatment considerably improved mesquite (*Prosopis juliflora*) tree growth in a sodic soil (pH: 10.4, ESP: 90) compared to control trees without gypsum suggesting that gypsum use could be of great help to proper tree growth in soils where initial pH and ESP are very high. Soil pH and salt content decreased while SOC and NPK contents improved with tree age; obviously due to litter fall and rhizospheric depositions (Singh *et al.*, 1989a). Although intercropping of Karnal grass reduced biomass production in mesquite, improvements in soil properties were faster and greater in mixed system than sole mesquite stand (Singh, 1995). Microbial biomass carbon, SOC, inorganic N and N mineralization rates were much higher in *Acacia*, *Eucalyptus* and *Populus*-based agri-silvicultural systems than both single species stands and rice-berseem rotation in a sodic soil.Soil carbon increased by 11-52% in integrated tree-crop systems (Kaur *et al.*, 2000). *Prosopis juliflora*, *Acacia nilotica* and *Casuarina equisetifolia* plantations significantly reduced soil pH, EC, ESP, and increased SOC and available NPK than control soil (pH_2: 8.8-10.5, ESP: 85-92) (Singh *et al.*, 2011). Investigations have also showed that cultivation of Karnal grass decreases the pH and ESP of degraded sodic soils due to *in situ* biomass decomposition and root-mediated improvements in soil quality (Batra*et al.* 1997; Kumar *et al.* 1994). Aromatic grasses like palmarosa (*Cymbopogonmartinii*) and lemon grass (*C. flexuosus*) also exerts ameliorative effects in sodic soils without any appreciable reductions in the essential oil yield. Factors like method and distance of planting, irrigation water availability, level of sodicity and economic value of a particular species determine the success of such agro-forestry interventions. Mesquite trees planted in gypsum (3 kg) and FYM (8 kg) ameliorated augerholes showed better growth than those planted in trenches in a highly sodic soil (ESP: 94) (Singh *et al.* 1988). Similarly, shoot and root growth of mesquite was considerably higher when planting was done in 90 cm deep augerholes compared to the trees planted to a shallow depth (30 cm) in trenches and pits. Compared to shallow roots in trenches and pits (upper 60 cm surface), augerhole planted trees produced deep penetrating roots (≈2.5 m deep) piercing the hard calcite layer (Singh *et al.* 1989b). In areas having limited fresh water availability, both salinity and water scarcity adversely affect the tree necessitating rainwater harvesting for supplemental irrigation. In many cases, agro-forestry species with high reclamation efficiency are often not adopted by the farmers due to poor economic returns. For example, *Acacia*-based system is more efficient in improving sodic soils than *Populus*- and *Eucalypus*-based systems, but B: C ratio is nearly double in the latter two systems (Singh *et al.* 1997). Considering the non-remunerative nature of some potential agro-forestry trees, studies have been conducted to identify the profitable fruit crops for sodic lands. Long-term observations have revealed the suitability of Indian jujube (*Ziziphus mauritiana*), jamun (*Syzygium cuminii*), guava (*Psidium guajava*), aonla (*Emblica officinalis*)and karonda (*Carissa congesta*) for highly sodic soils on north-western India. Saxena and Gupta (2006) observed that litchi cv. Rose Scented established well in semi-reclaimed sodic soils (pH: 8.5-9.0) when planted in sand and FYM (20 kg pit^{-1}) treated pits. Drip irrigation further improved plant growth by overcoming structural problems and low permeability.

Salt tolerant cultivars

Availability of high yielding cultivars capable of simultaneously tolerating excess salts, waterlogging and similar constraints could enable the farmers to obtain stable yields even in the absence of other salinity management interventions. Genetic improvement programme have led to the development of several STCs in staple crops like rice and wheat that are being cultivated over a large salt-affected area. Several potential genetic stocks have also been developed for the use as parents in future selection and hybridization programmes. Importance of high yielding STCs is best illustrated by rice, a salt-sensitive plant inefficient in controlling the influx of Na^+ through the roots, where high yielding STCs can provide a yield advantage of 1.5-2 t ha^{-1}. Many promising salt tolerant genotypes have also been identified in fruits (mango, bael, ber, guava and pomegranate) and vegetables (chilli, capsicum, okra and tomato). A technique for utilizing saline groundwater (ECIW up to 10 dS m^{-1}) in vegetables crops under low-cost protected structure has been standardized. A germplasm repository consisting of diverse medicinal and aromatic plants has been established in a partially reclaimed sodic land. Success has also been achieved in raising fruits like guava, bael, Indian jujube and pomegranate under saline shallow water table conditions that are otherwise considered to be unsuitable even for field crops. Taking a cue from less than expected adoption of the STCs released in different crops, efforts are also being made to develop high yielding STCs in a farmer participatory mode to convince the farmer clientele that their needs and preferences are being taken care of prior to varietal release. Such a farmer participatory rice varietal evaluation led to the identification and release of salt tolerant rice cv. CSR 43 for commercial cultivation in sodic areas of central IGP (Singh *et al.* 2014). Similar initiatives have been planned in other crops for expediting large-scale adoption of varieties being developed.

Sustainable management of reclaimed soils

Resodification refers to the reappearance of sodic patches in a sizeable area of reclaimed sodic soils. In Etawah district of Uttar Pradesh, out of total (3,905 ha) reclaimed sodic area, nearly one fourth had relapsed showing the signs of degradation (Yadav *et al.* 2010). It appears that lands in immediate vicinity of canals; especially those suffering from problems of hard sub-soil pan, drainage congestion and shallow watertable, are extremely susceptible to resodification. Similarly, resalinization of ameliorated saline lands can be ascribed to climate- and human-induced redistribution of salts to the surface soil. In both the cases, poor on-farm water management seems to accentuate the extent of salt build-up. Available evidence also suggests that indiscriminate irrigation and agro-chemical use have led to many second generation problems such as groundwater depletion and contamination, loss of soil organic carbon and nutrients, pest and disease outbreaks and crop residue burning in several parts of RWCS (rice wheat cropping systems) covering nearly 12 M ha area in India. These problems together with stagnant and/or declining crop yields have wide ranging ramifications for the food, environmental and economic security of the country. Several options are available to contain these problems. Adoption of conservation agriculture (CA) practices and the replacement of rice with low water requiring crops like maize may be helpful in achieving sustainable crop intensification in IGP of India. Gathala *et al.* (2014) reported that resource conservation technologies (RCTs) like reduced tillage, residue management and crop substitution led to increased system productivity and profitability. Choudhary *et al.* (2018) found that sustainable intensification of maize-wheat systems could result in considerable water and electricity saving while simultaneously increasing the crop and water productivity.

Management of coastal saline soils

Although coastal regions are quite rich in natural resources and biodiversity for supporting economic development, they are often hit by environmental hazards like storms and cyclones that cause massive destruction of life, infrastructure and natural resources. In so far as arable coastal lands are concerned, they suffer from constraints like excess accumulation of soluble and alkali salts, formation of acid sulphate soils, nutrient toxicities, seawater ingress into aquifers, frequent inundation by tidal waves, and a shallow (often saline) groundwater table. A heavy soil texture and water infiltration problems also make them vulnerable to erosion and sedimentation (Das, 2014). Sea level rise is a major climate change impact that will have wide ranging effects on coastal environments (IPCC, 2007). During the 21st century, the rate of sea level rise is projected to be several times higher than that measured over the past century. Recent projections suggest that sea level may be ~0.6 to 1.5 m higher than present by 2100, and ~2 m higher under extreme warming scenarios. In view of the large population living along the coastal lines, even small increases in sea level can have significant societal and economic impacts through increased coastal erosion, susceptibility to storm surges, inundation of low-lying areas, saltwater intrusion into groundwater, loss of coastal wetlands, and stresses on ecosystems and community infrastructure. Recently, a digital database of coastal salt-affected soils was prepared by integrating 31 geo-referenced maps in eight coastal states of India. Of total coastal salt-affected area (2.50 M ha), ~1.83 M ha was saline and the remainder (0.67 M ha) sodic. Among the states, Gujarat accounts for the largest area (50%) followed by West Bengal (17.6%), Tamil Nadu (12.7%), Andhra Pradesh (7.6%), Orissa (5.8%), Andaman and Nicobar Islands (3.0%), Maharashtra (2.0%) and Kerala (0.8%) (Mandal *et al.* 2018). Coastal salinity prevention and mitigation measures being implemented in various states of India can broadly be classified into 'salinity control', 'water recharge', 'land reclamation' and 'soil and crop management' interventions (CWC, 2017; Gururaja Rao, 2019). Some of the viable engineering measures for salinity prevention include protective embankments and bunds to reduce seawater inundation, seawater exclusion dams, bunds, bandharas and nalla plugs, surface drainage through field ditches, provision of seawater barriers to prevent seawater inflow into fresh aquifers, aquifer storage and recovery (ASR) and the use of skimming wells. In ASR, freshwater is injected into the aquifers during periods of high demand and is pumped back to the surface during the lean seasons. In areas where freshwater is underlain by saltwater, skimming wells can be a good option for keeping groundwater salinity below the acceptable limit. Similarly, check dams, recharge wells and tanks, and afforestation are considered efficient means to improving the recharge of fresh water aquifers. Land reclamation can be achieved by desiltation of lakes, anti-sea erosion measures, regulation of groundwater extraction, phytoremediation and application of soil amendments. A suit of doable agronomic practices and salt tolerant cultivars developed over the past few decades for the productive management of coastal salt-affected soils are discussed in the following sections. A number of technologies have been standardized to sustain crop production in coastal saline soils of the country. ‘Dorovu’ technology to skim fresh water floating on the saline water has gained immense popularity in many coastal regions. Other such technologies include *rabi* cropping in mono-cropped coastal saline soils, rainwater harvesting in dugout farm ponds, salt tolerant rice varieties (Sumati and Bhootnath), efficient nutrient management and integrated rice-fish culture.

EMERGING CONSTRAINTS

Several present and emerging challenges continue to plague agricultural sustainability in salt-affected environments. These problems and their sustainable solutions are briefly discussed in the following paragraphs:

Secondary salinity

Irrigation development has led to the development of waterlogged saline soils (secondary salinization) in many arid and semi-arid regions of the world. According to one estimate, the potential annual monetary loss due to secondary salinity is about Rs. 1669 million in Haryana state alone where approximately half a million hectare lands are affected by this problem (Datta and De Jong, 2002). By 2050, secondary salinity may affect 20 million ha area causing over three-fold increase in area under salt-affected soils as compared to the current estimate of 6.73 million ha. Keeping in view the severity of the problem, a set of technological interventions based on integrated watershed management, sub-surface drainage, cultivation of low water demanding crops, adoption of salt tolerant varieties and resource conservation practices, organic nutrient management and conjunctive use of fresh and saline waters are recommended for cost-effective and sustainable management of this problem (CSSRI, 2014).

Climate change impacts

Many direct and indirect effects of climate change- changes in precipitation patterns, higher atmospheric temperatures, increase in frequency of droughts, floods and storms, sea level rise, greenhouse gas emissions- would drastically limit agricultural productivity particularly in arid and semi-arid climates and coastal regions. Anticipated increase in warming and evapo-transpiration coupled with decrease in rainfall could have adverse consequences in dry (arid and semi-arid climates) regions while predicted sea level rise and the consequent increase in the process of saline water intrusion and the increased frequency of cyclonic storms would undermine the sustainability of many coastal agricultural systems. Globally, agriculture and related activities are major contributors to global greenhouse-gas emissions as agriculture alone accounts for about 10–12% of global emissions which is expected to substantially increase by 2030 (Friel *et al.*, 2009). While land-use changes such as deforestation account for large emissions of CO_2, agricultural activities are responsible for about 50 and 70% emissions of methane and nitrous oxide, respectively of the total anthropogenic emissions of these gases (Cole, *et al.*, 1997). The long-term adaptation strategies suggested to overcome these challenges are based on sustainable soil and crop management practices (resource conservation practices such as zero tillage, integrated water and nutrient management, efficient irrigation techniques and adoption of resource use efficient and stress resilient crop varieties (Keane *et al.*, 2009) with an equal focus on restoring the vast tracts of moderately to severely degraded lands (including salt-affected soils) which offer an immense opportunity for carbon sequestration (Cole, *et al.*, 1997).

Resodification and resalinization

Recentreports concerning resodification of gypsum-amended sodic soils (Gharaibeh *et al.*, 2014) and resalinization of reclaimed saline soils (Valipour, 2014) are worrying as they could potentially offset the gains achieved in the past. Resodification refers to the reappearance of sodic patches in amended (through use of gypsum or other amendments such calcium chloride, sulfuric acid and phosphogypsum) sodic soils (Garg, 2002; Gharaibeh *et al.*, 2014). The ameliorated soils support crop production for a good number of years, but certain adverse conditions such as congestion in natural drainage, shallow water tables and seasonal fluctuations in water table, seepage from canals and subsequent water logging of fields, repeated droughts and practice of crop fallow induce the reappearance of sodicity rendering them unsuitable for crop production (Fekete *et al.*, 2002). These problems can be minimized to a great extent by adopting efficient irrigation and drainage techniques, balanced fertilizer use with emphasis on organic manures, cultivation of low water requiring crops and resource conservation technologies.

Declining availability of amendments

Use of chemical amendments to reclaim sodic soils is increasingly becoming a costly proposition for the farmers in many developing countries due to increased usage by industry and reductions in government subsidies to farmers for their purchase. Restricted supply and poor quality of these amendments have also discouraged their use (Qadir and Oster, 2004). In this backdrop, prioritized research on alternative approaches such as phytoremediation using salt tolerant trees, identification of efficient microbial inoculants and organic amendments (green manures, FYM and crop residues), development of alternative amendments (pressmud, pyrite and distillery spent wash), alternate land uses and diversification through viable agro-forestry models, fruit trees and other horticultural crops and development of salt tolerant varieties has given encouraging results (Sharma and Chaudhari, 2012).

Water scarcity

Conventional approaches to ameliorate the saline and sodic soils (leaching and gypsum application followed by irrigation, respectively) require huge quantities of fresh water and its limited availability would necessitate the development of alternative strategies for using poor quality waters to reclaim and productively utilize them. India has 4.2% share of global water resources and supports about 16.7% of the global population. Agriculture alone accounts for about 85% water use in the country and the remainder 15% is used by the domestic and industrial sectors. Good quality water availability in desired quantities is of utmost importance for higher agricultural productivity. Besides continuous decrease in the availability of fresh water resources, many parts in India suffering from water scarcity are also usually underlain by poor quality groundwater and the maximum area under saline and brackish groundwaters occurs in the arid and semi-arid regions of Rajasthan, Punjab, Haryana, Delhi and Uttar Pradesh (Singh, 2009). Research priorities have been outlined to standardize the protocols for use of polluted waters in reclamation and significant achievements have been made with respect to ground water recharge, storage and subsequent use of rain water through land modification and other technological interventions such as *dorouv* technology to skim fresh water floating on the saline water.

CONCLUSIONS AND FUTURE PERSPECTIVES

Although rapid strides have been made in the management and use of saline and sodic soils, fast changing agricultural scenario and the emerging challenges have necessitated a shift in the conventional approaches to sustain agricultural productivity in resource scarce and risk prone saline environments. Further refinements in mapping and characterization of salt-affected regions with the aid of emerging technologies such as solute transport modelling and use of air-borne geophysical sensors is the need of time. The existing technologies, particularly chemical amendments-based reclamation packages and sub-surface drainage require a thorough revision to make them more suitable for different operating environments. Concerted efforts are also required to develop cheap and environment-friendly alternatives to gypsum for reclaiming the sodic soils. Identification and development of multiple stress tolerant genotypes is the high need of time. The tested resource conservation technologies need to be replicated in farmers' field in a big way. Research and development should go hand in hand for promoting the widespread adoption of proven technologies in an integrated manner. Vigorous efforts are required for capacity building of the farmers in salt-affected regions to enable them to effectively deal with the present and future constraints.

BIBLIOGRAPHY

Batra, L., Kumar, A., M qAanna, M. C. and Chhabra, R. (1997). Microbiological and chemical amelioration of alkaline soil by growing Karnal grass and gypsum application. *Experimental Agriculture* **33**, 389-397.

Chhabra, R. and Thakur, N. P. (1998). Lysimeter study on the use of biodrainage to control waterlogging and secondary salinization in (canal) irrigated arid/semi-arid environment. *Irrigation and Drainage Systems* **12**, 265-288.

Choudhary, K. M., Jat, H. S., Nandal, D. P., Bishnoi, D. K., Sutaliya, J. M., Choudhary, M., Singh, Y., Sharma, P. C. and Jat, M. L. (2018). Evaluating alternatives to rice-wheat system in western Indo-Gangetic Plains: Crop yields, water productivity and economic profitability. *Field Crops Research* **218**: 1-10.

Choudhary, O. P., Ghuman, B. S., Thuy, N. and Buresh, R. J. (2011). Effects of long-term use of sodic water irrigation, amendments and crop residues on soil properties and crop yields in rice–wheat cropping system in a calcareous soil. *Field Crops Research* **121:** 363-372.

Cole, C. V., Duxbury, J., Freney, J., Heinemeyer, O., Minami, K., Mosier, A. *et al.* (1997). Global estimates of potential mitigation of greenhouse gas emissions by agriculture. *Nutrient cycling in Agroecosystems* **49(1)**, 221-228.

CSSRI.(2013). Annual Report 2013-14, Central Soil Salinity Research Institute, Karnal, India.

CSSRI.(2014). CSSRI Vision 2050. Central Soil Salinity Research Institute, Karnal.

Datta, K. K. and De Jong, C. (2002). Adverse effect of waterlogging and soil salinity on crop and land productivity in northwest region of Haryana, India. *Agricultural water management* **57(3):** 223-238.

Devi, S., Angrish, R., Madaan, S., Toky, O. P. and Arya S. S. (2016). Sinker root system in trees with emphasis on soil profile. *In:* Plant-Microbe Interaction: An Approach to Sustainable Agriculture (Choudhary D. *et al.* Eds.). Springer, Singapore.

FAO and ITPS. 2015. Status of the World's Soil Resources (SWSR), Main Report. Food and Agriculture Organization of the United Nations and Intergovernmental Technical Panel on Soils, Rome, Italy.

Fekete, J. and Feher, O. (2002).The results of amelioration of sodic and alkaline soils. In *Man and soil at the Third Millennium. Proceedings International Congress of the European Society for Soil Conservation, Valencia, Spain, 28 March-1 April, 2000. Volume 2* (pp. 1525-1533). GeoformaEdicions, SL.

Fereres, E. and Soriano, M. A. (2007). Deficit irrigation for reducing agricultural water use. *Journal of Experimental Botany* **58:** 147-159.

Friel, S., Dangour, A. D., Garnett, T., Lock, K., Chalabi, Z., Roberts, I. *et al.* (2009). Public health benefits of strategies to reduce greenhouse-gas emissions: food and agriculture. *The Lancet* **374:** 2016-2025.

Garg, V. K. 2002. Sustainable rehabilitation of sodic soils through biological means—A case study. In 12th ISCO Conference, Beijing (pp. 149-155).

Gathala, M. K., Kumar, V., Sharma, P. C., Saharawat, Y. S., Jat, H. S., Singh, M., Kumar, A., Jat, M. L., Humphreys, E., Sharma, D. K., Sharma, S. and Ladha, J. K. (2014). Optimizing intensive cereal-based cropping systems addressing current and future drivers of agricultural change in the Northwestern Indo-Gangetic Plains of India. *Agriculture, Ecosystems & Environment* **187:** 33-46.

Gharaibeh, M. A., Rusan, M. J., Eltaif, N. I., &Shunnar, O. F. (2014). Reclamation of highly calcareous saline-sodic soil using low quality water and phosphogypsum. *Applied Water Science* **4(3):** 223-230.

Gupta, S. and Singh. J. P. (2014). Multiple well point system for irrigation and drainage for south-western districts of Punjab. *Journal of Research* **51:** 175-180.

ICAR-CSSRI. (2017a). Annual Report, 2016-17, ICAR-Central Soil salinity Research Institute, Karnal-132001, India.

Kaur, B., Gupta, S. R. and Singh, G. (2000). Soil carbon, microbial activity and nitrogen availability in agroforestry systems on moderately alkaline soils in northern India. *Applied Soil Ecology* **15:** 283-294.

Keane, J., Page, S., Kergna, A. and Kennan, J. (2009). Climate change and developing country agriculture: An overview of expected impacts, adaptation and mitigation challenges, and funding requirements. *Issue Brief* **2:** 1-49.

Kumar, A., Batra, L. and Chhabra, R. (1994) Forage yield of sorghum and winter clovers as affected by biological and chemical reclamation of a highly alkaline soil. *Experimental Agriculture* **30,** 343-348.

Lewis, S. M. and Kelly, M. (2014). Mapping the potential for biofuel production on marginal lands: differences in definitions, data and models across scales. *ISPRS. International Journal of Geo-Information* **3(2):** 430-459.

Makoi, J. H. and Ndakidemi, P. A. (2007). Reclamation of sodic soils in northern Tanzania, using locally available organic and inorganic resources. *African Journal of Biotechnology* **6:** 1926-1931.

Mandal, S., Burman, D., Mandal, U. K., Lama, T. D., Maji, B. and Sharma, P. C. (2017). Challenges, options and strategies for doubling farmers' income in West Bengal- Reflections from coastal region. *Agricultural Economics Research Review* **30:** 89-100.

Mandal, S., Sarangi, S. K., Burman, D., Bandyopadhyay, B. K., Maji, B., Mandal, U. K. and Sharma, D. K. (2013). Land shaping models for enhancing agricultural productivity in salt affected coastal areas of West Bengal–an economic analysis. *Indian Journal of Agricultural Economics* **68:** 389-401.

Mandal, A. K., Reddy, G. O., Ravisankar, T. and Yadav, R. K. (2018). Computerized database of salt-affected soils for coastal region of India. *Journal of Soil Salinity & Water Quality* **10:** 1-13.

Meena, M. D., Joshi, P. K., Jat, H. S., Chinchmalatpure, A. R., Narjary, B., Sheoran, P. and Sharma, D. K. (2016). Changes in biological and chemical properties of saline soil amended with municipal solid waste compost and chemical fertilizers in a mustard–pearl millet cropping system. *Catena* **140:** 1-8.

NRSA. (2014). Salt-affected and waterlogged areas of India. National Remote Sensing Centre, Hyderabad. Available on http://bhuvan.nrsc.gov.in/gis/thematic/tools/document/ALK/alk.pdf.

Purushothaman, C. S., Raizada, S. Sharma, V. K., Harikrishna, V., Venugopal, G., Agrahari, R. K., Rahaman, M., Hasan, J. and Kumar, A. (2014). Production of tiger shrimp (Penaeusmonodon) in potassium supplemented inland saline sub-surface water. *Journal of Applied Aquaculture* **26:** 84-93.

Qadir, M. and Oster, J. D. (2004). Crop and irrigation management strategies for saline-sodic soils and waters aimed at environmentally sustainable agriculture. *Science of the Total Environment* **323:** 1-19.

Ramankutty, N., Mehrabi, Z., Waha, K., Jarvis, L., Kremen, C., Herrero, M. And Rieseberg, L. H. (2018). Trends in global agricultural land use: implications for environmental health and food security. *Annual review of plant biology* **69:** 789-815.

Ray, D. K., Mueller, N. D., West, P. C. and Foley, J. A. (2013). Yield trends are insufficient to double global crop production by 2050. *PlOS ONE* **8(6):** e66428.

Sadras, V. O. (2009). Does partial root-zone drying improve irrigation water productivity in the field? A meta-analysis. *Irrigation Science* **27:** 183-190.

Saxena, C. K. and Gupta, S. K. (2006). Uniformity of water application under drip irrigation in litchi plantation and impact of pH on its growth in partially reclaimed alkali soil. ISAE *Journal of Agricultural Engineering* **43:** 1-9.

Sepaskhah, A. R. and Ahmadi, S. H. (2010). A review on partial root-zone drying irrigation. *International Journal of Plant Production* **4,** 241-258.

Sharma, D. K. and Chaudhari, S. K. (2012). Agronomic research in salt affected soils of India: an overview. Indian *Journal of Agronomy* **57:** 175-185.

Sharma, D. K. and Sharma, D. R. (1999). Sustainable use of poor quality water with proper scheduling of irrigation and nitrogen levels to rice crop. *Water Science and Technology* **40:** 111-114.

Sharma, D. K. and Singh, K. N. (1993). Effect of irrigation on growth, yield and evapotranspiration of mustard (Brassica juncea) in partially reclaimed sodic soils. *Agricultural Water Management* **23:** 225-232.

Sharma, D. K., Kumar, A. and Singh, K. N. (1990). Effect of irrigation scheduling on growth, yield and evapotranspiration of wheat in sodic soils. *Agricultural Water Management* **18:** 267-276.

Sharma, D. P. and Rao, K. V. G. K. (1998). Strategy for long term use of saline drainage water for irrigation in semi-arid regions. *Soil and Tillage Research* **48:** 287-295.

Sharma, D. P., Singh, K. N. and Kumbhare, P. S. (2005). Response of sunflower to conjunctive use of saline drainage water and non-saline canal water irrigation. *Archives of Agronomy and Soil Science* **51:** 91-100.

Sharma, P. C., Kaledhonkar, M. J., Thimappa, K. and Chaudhari, S. K. (2016a). Reclamation of waterlogged saline soils through subsurface drainage technology. ICAR-CSSRI/Karnal/ Technology Folder/ 2016/02, p. 4.

Sharma, P. C., Thimappa, K., Kaledhonkar, M. J. and Chaudhari, S. K. (2016b). Reclamation of alkali soils through gypsum technology. ICAR–CSSRI/Karnal/Technology Folder/2016/01, p.4.

Singh, G. (2009). Salinity-related desertification and management strategies: Indian experience. *Land Degradation and Development* **20:** 367-385.

Singh, G., Abrol, I. P. and Cheema, S. S. (1988). Agroforestry on alkali soil: Effect of planting methods and amendments on initial growth, biomass accumulation and chemical composition of mesquite (*Prosopisjuliflora* (SW) DC) with inter-space planted with and without Karnal grass (*Diplachnefusca Linn.* P. Beauv.). *Agroforestry Systems* **7:** 135-160.

Singh, G., Abrol, I. P. and Cheema, S. S. (1989a). Effects of gypsum application on mesquite (*Prosopisjuliflora*) and soil properties in an abandoned sodic soil. *Forest Ecology and Management* **29:** 1-14.

Singh, G., Abrol, I. P. and Cheema, S. S. (1989b). Effects of spacing and lopping on a mesquite (*Prosopis juliflora*)–Karnal Grass (*Leptochloa fusca*) agroforestry system on an alkaline soil. *Experimental Agriculture* **25:** 401-408.

Singh, G., Singh, N. T., Dagar, J. C., Singh, H. and Sharma, V. P. (1997). An evaluation of agriculture, forestry and agroforestry practices in a moderately alkali soil in northwestern India. *Agroforestry Systems* **37:** 279-295.

Singh, Y. P., Nayak, A. K., Sharma, D. K., Gautam, R. K., Singh, R. K., Singh, R., Mishra, V. K., Paris, T. and Ismail, A. M. (2014). Farmers' participatory varietal selection: A sustainable crop improvement approach for the 21st century. *Agroecology and Sustainable Food Systems* **38:** 427-444.

Singh, Y. P., Singh, G. and Sharma, D. K. (2011). Ameliorative effect of multipurpose tree species grown on sodic soils of Indo-Gangetic alluvial plains of India. *Arid Land Research and Management* **25:** 55-74.

SubbaRao, P. V. and Mantri, V. A. (2006). Indian seaweed resources and sustainable utilization: Scenario at the dawn of a new century. *Current Science* **91:** 164-174.

Sundha, P., Basak, N., Rai, A. K., Yadav, R. K., Sharma, D. K. and Sharma, P. C. (2017). N and P release pattern in saline-sodic soil amended with gypsum and municipal solid waste compost. *Journal of Soil Salinity and Water Quality* **9:** 145-155.

Tyagi, N. K. (2003). *Managing Saline and Alkaline Water for Higher Productivity. In:* Water Productivity in Agriculture: Limits and Opportunities for Improvement (Kijne, J. W. *et al.* Eds). CAB International pp. 69-87.

UNCCD. 2017. The Global Land Outlook, First Edition. United Nations Convention to Combat Desertification, Bonn, Germany

Valipour, M. 2014. Drainage, waterlogging, and salinity. *Archives of Agronomy and Soil Science* **60:** 1625-1640.

Verma, C. L., Singh, Y. P., Damodaran, T. and Mishra, V. K. (2015). *Integrated farming system model for flood prone, waterlogged and waterlogged sodic areas*. In: Advanced techniques for bio-remediation and management of salt affected soils (*Eds.* Arora, S., Singh, Y.P. and Singh, A. K.), Training Manual, ICAR-CSSRI, RRS, Lucknow, p.1-261.

Wicke, B., Smeets, E., Dornburg, V., Vashev, B., Gaiser, T., Turkenburg, W. And Faaij, A. (2011). The global technical and economic potential of bioenergy from salt-affected soils. *Energy & Environmental Science* **4(8):** 2669-2681.

Yadav, M. S., Yadav, P. P. S., Yaduvanshi, M., Verma, D. and Singh, A. N. (2010) Sustainability assessment of sodic land reclamation using remote sensing and GIS. *Journal of the Indian Society of Remote Sensing* **38,** 269-278.

An Innovative Water Management for Cropping Intensification in the Coastal Ganges Delta: A Case Study in a Medium-Saline Polder of Southwest Bangladesh

MANORANJAN KUMAR MONDAL*

Former Senior Scientist, Bangladesh Rice Research Institute (BRRI), Bangladesh
Former Project Scientist, International Rice Research Institute (IRRI), Bangladesh

**Corresponding author:* E-mail: m.mondal@irri.org

The Ganges coastal zone of Bangladesh comprises low lying lands within a dense network of large rivers and their distributaries (canals). The rivers are tidal and this effect extends about 150 km inland, with diurnal water level fluctuations of 2 to 4 m in the southwest Bangladesh. Salinity of the rivers increases during the dry season, more so closer to the coastline and in the southwest (Khan *et al.* 2015). The water resources of the coastal zone are vital for crop production, ecosystem sustenance and livelihoods. More than 30% of the cultivable land of Bangladesh is in the coastal zone (SRDI, 2010). Of the 2.85 Mha of coastal and offshore lands, about 1.2 Mha of agricultural lands were enclosed in 139 polders in the 1960s and 1970s, to prevent inundation at high tide during the rainy season and enable production of a tall statured, low yielding *aman* (wet season rice) crop, and to prevent saline water intrusion during the dry season. Poldering involved building large embankments around the perimeter of the islands between the rivers. Inside the polders, there are also dense, natural drainage networks (*khals* or canals), and some of the larger internal canals were connected to the surrounding rivers by sluice gates installed in the polder embankments (Fig. 1). Thus, with judicious management of the sluice gates, water can be taken into the polders at high tide or drained from the polders at low tide. However, despite enormous investment in the polders, cropping intensity and productivity are much lower than in other parts of Bangladesh (BBS, 2014). As a result, the polders (population about 8 million) are home to some of the world's poor and most vulnerable people. Kabir *et al.* (2014) showed that almost 80% of rural people in the polders are living below the poverty line (\$1.25 person^{-1}day^{-1}).

Although Bangladesh as a whole is currently self-sufficient in rice production, this is not the case for the coastal zone (MoA-FAO, 2013; Tuong *et al.*, 2014). The country faces enormous challenges to maintain food self-sufficiency for its growing population, as there is little scope to further increase cropping system intensity, except in the underutilized coastal zone lands, and especially the polders. Unlike the rest of Bangladesh, the farmers in the polders have not widely adopted modern high yielding rice varieties (HYV) because their shorter stature makes them unsuitable for the high water depths (20-70 cm) which often prevail during the rainy season. Yet the polder ecosystems provide an excellent opportunity to greatly reduce water logging as elevation of most of the lands is higher than the low tide level of the rivers (Khan *et al.*, 2015). In the coastal zone the traditional low yielding *aman* crop (2.0-3.5 t ha^{-1}) is sometimes followed by a low input, low yielding relay-sown grasspea (0.5^{-1}.0 t ha^{-1}) crop and/or preceded by an early rainy season aus rice (2.5-3.5 t ha^{-1}) crop or late sown (mid February to early March) sesame and mungbean (0.5^{-1}.0 t ha^{-1}) (Mondal *et al.*, 2015a). The *rabi* crops are often damaged by the early *kharif* rains, and by cyclones at or near maturity. Moreover, many fields remain flooded until December, delaying harvest of *aman* and establishment of *rabi* crops. The late harvest of the local *aman* varieties and waterlogged soil prevent the cultivation of high yielding *rabi* crops such as maize, sunflower and wheat which need to be established in early December for maximum yield. Thus large areas of the coastal land lie fallow during the dry season (Hasan *et al.*, 2013).

The feasibility of increasing productivity in the polders by intensifying and diversifying cropping systems has been shown by many researchers in recent years (Mondal *et al.*, 2010, Ritu *et al.*, 2015, Mondal *et al.*, 2015a, Bhattacharya *et al.*, 2019, Yadav *et al.*, 2020). However, despite considerable investment and efforts from government, non-government and international organizations, there has been little adoption of improved production systems in the polder zone. Achieving large-scale adoption requires proper investment in water management infrastructure in the coastal Ganges delta (Tuong *et al.*, 2014). This should be guided by a new paradigm, with fundamental changes in thinking about the polders and their roles. Each polder must be considered as an integrated water management unit, rural infrastructures (roads) should be capitalised on as boundaries of water management units, and improving drainage should be regarded as the key intervention and the entry point for cropping intensification and diversification. At low tide that occur twice daily, the river level is generally lower than the land level within the polders (Khan *et al.*, 2015), creating opportunities for drainage of excess water (as a result of heavy rainfall) by gravity to a level which would allow good growth and yield of HYV *aman* rice (Mondal *et al.*, 2015b, Bhattacharya *et al.*, 2019, Yadav *et al.*, 2020). Furthermore, drainage of the earlier maturing HYV shortly prior to harvest would allow the soil to dry sufficiently for timely establishment of *rabi* crops. However, these opportunities have not yet been recognized. Therefore the present study sought to work with pilot communities in a medium-saline polder of southwest Bangladesh to demonstrate the benefits of improved water management, especially drainage, and how to achieve this for adoption of improved production systems for food security of the climate-vulnerable communities of the coastal Ganges delta.

Study site

The study was undertaken in three pilot watersheds in Khatakhali sub-polder or catchment area (~600 ha) in polder 30 in southwest Bangladesh (Fig. 1), in partnership with the communities of three villages in Batiaghata upazila, Khulna district. The study was conducted from January 2012 to June 2014 at Kismat Fultola village in collaboration with 36 farmers, and from January 2015 to June 2016 at Fultola and Basurabad in collaboration with 52 and 25 farmers, respectively, together with the community water management groups (WMG) at village level and the water management association (WMA) at polder level. At each village, bounded water management unit (WMU) were created by taking advantage of rural roads and erecting earthen levees to complete the boundaries. Gated drainage outlets connecting the WMUs to the natural drainage system (canals) were also installed. The area of the watersheds at Kismat Fultola, Fultola and Basurabad was 6, 21 and 4 ha, respectively. The watershed at Kismat Fultola was very near (0.5 km) the sluice gate (Khatakhali regulator), while those at Basurabad (2.5 km) and Fultola (5.5 km) were further away in terms of length of the drainage route. The sluice gate was operated by the WMA to either let water in (at high tide) to irrigate *aman* rice, or to enable drainage (at low tide) of excess water from rainfall and drainage before harvest of the rice to facilitate early/timely establishment of *rabi* crops.

Development of collaboration with the communities

Several meetings were conducted with the pilot watershed farmers, neighboring farmers, officials of the local WMGs and WMA, members of the WMGs, and local government (Union Parishad) to discuss the community crop and water management proposal. Several meetings were also organized with the WMG officials and pilot watershed farmers to decide on the cropping systems to be practiced in the watersheds and on the water management (mainly management of the sluice gate to enable the agreed cropping systems). The agreed (informal) water management and cropping systems involved:

- HYV *aman*, using non photoperiod sensitive, medium duration varieties ($135^{-1}45$ d) which would be transplanted (using 25-30 d old seedlings) in the first week of August to enable harvest by the third week of November
- Drainage during the *aman* crop whenever the water was too deep (taking into account the development stage and height of the crop) by systematically opening the sluice gate at low tide to drain until the desired field water depth was achieved
- Terminal drainage of the *aman* crop – drainage of the standing water (if any) in early November, about two weeks before harvest maturity
- *Rabi* crops of maize and sunflower to be sown in mid December, and sesame and mungbean to be sown in late January to early February
- Establishment of maize and sunflower by dibbling into the moist soil in December; tillage for sesame and mungbean in late January/early February (once the soil had dried enough for tillage using a power tiller driven by a 2-wheel tractor) followed by sowing in the first week of February

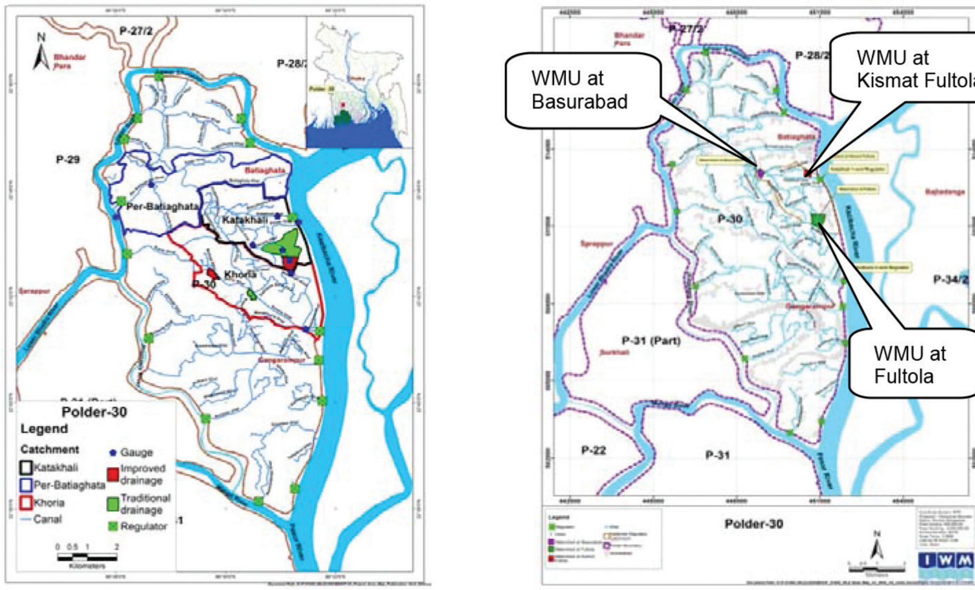

Fig. 1. Map of polder 30 showing three catchments of the Katakhali, Khoria and Per Batiaghata regulators (left) and the pilot watersheds/ water management units (WMUs) at Kismat Fultola, Fultola and Basurabad villages within Katakhali catchments (right).

Rainfall and water depth monitoring

A standard rain gauge was installed in the vicinity of the pilot WMUs and 10-20 staff gauges were installed on a grid within the WMUs. These devices were read each morning between 9 and 11 am, and average water depth was determined. In 2015, the water level in the Kazibacha and lower Salta rivers was determined from June to December. Automated pressure gauges were installed in the rivers to monitor tidal dynamics at 10-minute intervals. The data were used to develop drainage hydrographs and to establish the rise and recession characteristics of the water surfaces relative to mean sea level (MSL).

Training on crop cultivation and sluice gate operation

Formal training on the production of HYV *aman* varieties and on drainage management was provided to the farmers prior to the start of the rainy season. Enough seed of HYV rice and fertilizer were provided to each farmer to grow HYV on all of the land that they cultivated in the WMUs, using recommended practice (BRRI, 2010) (except in 2012 when no fertilizer was given). Prior to rice harvest, training was provided in the cultivation of maize and sunflower, and seed and fertilizer were provided to farmers interested in growing these crops. The farmers were also mentored during the growth season of each crop, on-farm at times of key activities such as transplanting, fertilizer application, and sowing of *rabi* crops. This included guidance on water management, especially drainage in times of excessive water depth following rainfall, prior to topdressing nitrogen (N) fertilizer, and two weeks prior to rice harvest.

Achievement and Lessons Learnt

Water management

Cropping Year 1 (July 2012-June 2013) – Kismat Fultola

During the 2012 *aman* crop, there were two rainfall events in excess of 250 mm each, during 8^{-1}4 August (immediately after transplanting), and during 3-5 September (Fig. 2a); both events led to flooding of the entire polder including the pilot WMU. The farmers successfully drained the excess water within 3 to 4 days on both occasions, in collaboration with the WMG officials, whereas other parts of the polder were waterlogged for 7 to 10 days. At the time of the first heavy rainfall, the HYV seedlings were only ~15 cm tall and were completely submerged. The mean water depth in the pilot watershed was ~23 cm on 6 September 2012 following the second heavy rainfall

(Fig. 2a). At this stage the height of the HYV plants was 20-25 cm and thus they were almost completely submerged. The water depth in the pilot watershed was lowered to ~11 cm within 3 days. As a result of rapid drainage on both occasions, the HYV rice in the pilot WMU was not damaged, whereas the crops in some parts of the polder were damaged and many farmers had to re-plant using older seedlings, increasing their production cost and decreasing yield due to late planting with older seedlings.

Although the farmers were very efficient in handling the drainage of flood water during the *aman* crop, they were unable to implement the terminal drainage plan because about 50% of the farmers planted long-duration traditional rice varieties instead of HYV. The plan was to drain the rice field in the first week of November. But at that time, the traditional rice was only in the early grain filling stage, and instead of draining, more water was brought in to the field (Fig. 2a) to finish the traditional rice crops which were scattered across the WMU. As a result, soil drying was delayed.

Cropping Year 2 (July 2013-June 2014) – Kismat Fultola

Following the first years' experience, a sub-WMU (1.3 ha) was created in 2013 within the 6 ha pilot WMU at Kismat Fultola, near the drainage outlet, in which farmers (6 farmers) agreed to properly implement the water management and cropping plan. There were no high rainfall events in 2013 and water depth during the *aman* crop fluctuated between 2 and 10 cm (Fig. 2b). The farmers drained three times to topdress N fertilizer. Terminal drainage from the sub-WMU was done on 31 October 2013, about two weeks before harvest, as planned, compared with 23-26 November in the rest of the 6 ha WMU where traditional rice was cultivated by the majority of farmers. As a result, the sub-WMU farmers were able to establish *rabi* crops about a month earlier (mid-December 2013-early January 2014) than those of rest of the catchment area of Katakhali regulator.

Cropping Year 3 (July 2015-June 2016) – Fultola and Basurabad

Two study sites were chosen at Fultola and Basurabad to implement water management and cropping trials during 2015 and 2016 on a much larger scale and involving the larger community. The sites were far from Khatakhali sluice gate to test the ability to implement improved drainage well inside the polder.

There were no high rainfall events in 2015 and water depth in the WMUs at Fultola and Basurabad fluctuated between 2 and 35 cm during the *aman* season (Fig. 2c). Almost all the WMU farmers cultivated HYV rice in 2015 and drained twice to topdress N fertilizer. However, terminal drainage was delayed by two weeks, mainly because of the cultivation of traditional rice by the majority of farmers within the rest of the Katakhali catchment (605 ha) and the long drainage route between the pilot WMUs and Khatakhali sluice gate. Notwithstanding, drainage of the pilots took place two weeks earlier than in the rest of the catchment. As a result, the pilot WMU farmers of Fultola and Basurabad were able to establish *rabi* crops four to six weeks earlier (mid-December 2015-late January 2016) than most farmers in the rest of the catchment (late February 2016).

During the *rabi* season, a storm on 24-25 February 2016 deposited ~100 mm of rain (Fig. 5c) which caused severe waterlogging throughout the polder. In the pilot WMUs, the farmers and WMG officials worked together and drained the water by digging small field drains and opening the sluice gate at low tide. They had earlier ignored advice to construct drains at the time of sowing.

Crop management and performance

Yields of all crops in pilot WMUs were determined by harvesting a total area of 10 m^2 from 3 locations within each field. Yield of crops outside the WMU were as reported by the farmers.

Cropping Year 1 (July 2012-June 2013) – Kismat Fultola

The farmers transplanted rice (HYV and traditional) in mid-August, within the recommended time. Those who grew HYV adopted wider row spacing than recommended, and applied no or very little fertilizer. Therefore, yield of HYV rice (as reported by the farmers) was low (~3 t ha^{-1}) and similar to that of the traditional varieties. But those

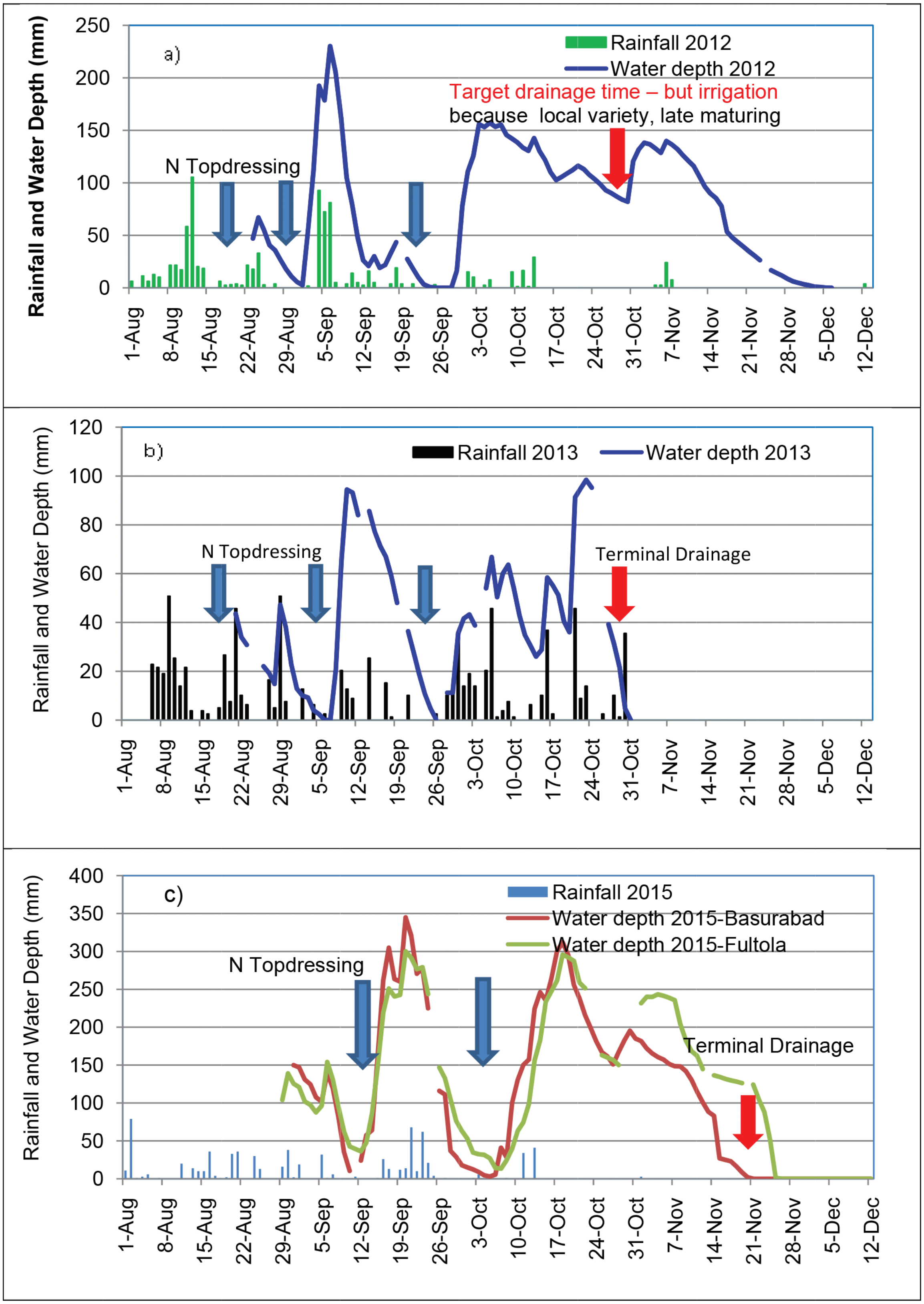

Fig. 2. Rainfall and water depth in the pilot water management units (WMUs) in the aman seasons of 2012 (a), 2013 (b) and 2015 (c) showing drainage for N topdressing (blue arrows) and terminal drainage (red arrows).

(6 farmers) who applied recommended fertilizer harvested about 5 t ha^{-1} (Fig. 3). The HYV rice was harvested in the second half of November, and the traditional rice was harvested in the second half of December. As a result of delayed drainage and harvest of the traditional rice, *rabi* crop establishment was delayed until the second half of February/early March 2013. About 60% of the farmers cultivated traditional sesame (broadcast on ploughed land) with no fertilizer input or management other than weeding. The rest of the farmers cultivated improved varieties of sesame, mungbean, maize and sunflower. The project provided good quality seeds of the improved varieties, and the farmers bought and applied fertilizer, but at about half the recommended rate.

While most *rabi* crops were sown late, two farmers established sunflower on the 1st January 2013 by dibbling into the moist soil. But, despite moderate to good growth and development, they did not take proper care of the crops (no fertilizer, irrigation or weeding). These crops were harvested before the end of April with a yield of 1.45 t ha^{-1} (about half the expected yield with proper management) (Fig. 4).

Initially, growth of the late sown *rabi* crops (sesame, mungbean, sunflower and maize) was poor due to lack of rainfall and inability to irrigate due to high salinity of the river/canal water, but all crops recovered strongly after rainfall in mid-March and mid-April (Fig. 5a). Just when the farmers' hopes for a good harvest were rising, a cyclone (Mohasen) developed in the Bay of Bengal and made landfall in mid-May, bringing huge rainfall (420 mm). As a result, all the *rabi* crops in the entire polder were damaged or destroyed due to waterlogging (Mondal *et al.*, 2015b) with two exceptions - the early sown sunflower in the pilot WMU, which had already been harvested, and the late sown maize and sunflower crops of two farmers near the drainage outlet. The farmers were able to drain these crops and harvested 5.43 t ha^{-1} maize and 1.45 t ha^{-1} sunflower. Yield of both these crops was low as the maize farmer applied only ~50% of the recommended fertilizer, and the sunflower farmer did not apply any fertilizer (although weeding and irrigation were done). Many farmers abandoned harvesting sesame, but some (42%) picked mature but poor quality pods from the waterlogged fields (average yield 0.14 t ha^{-1}) (Fig. 4).

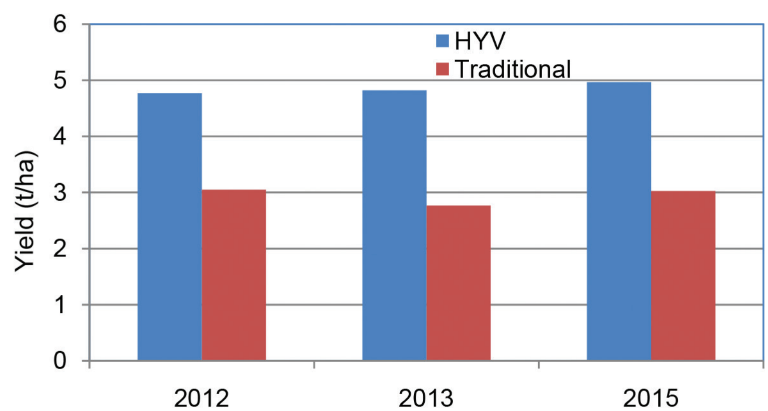

Fig. 3. Yield of traditional and HYV rice in the pilot watersheds.

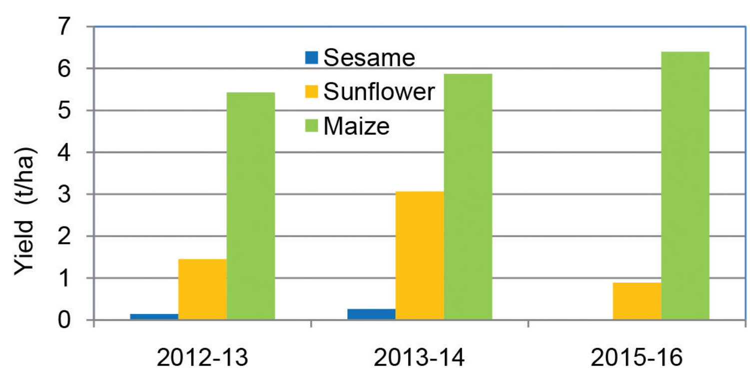

Fig. 4. Yield of rabi crops in the pilot watersheds.

Cropping Year 2 (July 2013-June 2014) - Kismatfultola

The farmers of the sub-watershed transplanted HYV *aman* on 7 August 2013, and implemented recommended fertilizer and crop management practices (BRRI 2010). The aman crop was harvested on 27 November with an average yield of about 5.0 t ha^{-1} (Fig. 3). The farmers rest of the WMU (other than sub-WMU farmers) and adjacent areas of the main WMU cultivated both HYV and traditional rice, using no or very little fertilizer, and harvested around mid-January. Average yield of traditional and HYV rice was 2.8 t ha^{-1} and 3.5 t ha^{-1}, respectively (Mondal *et al.*, 2015b).

During the following *rabi* season, maize and sunflower were cultivated in the sub-WMU by dibbling into the moist soil on 10 December 2013. The farmers in the main WMU area sowed sesame and mungbean during the second half of February 2014 (more than 2 months later).

The 2013-14 *rabi* season was unusually dry, with only 36 mm rainfall from 1 December 2013 to 30 April 2014 (Fig. 5b). As a result, establishment, growth and development of the late-established sesame and mungbean were very poor. The crops were partially damaged by waterlogging as a result of 245 mm rain in late May and early June 2014. The yield of sesame and mungbean was only 0.32 and 0.26 t ha^{-1}, respectively (Mondal *et al.* 2015b). In contrast, establishment and growth of the early-established maize and sunflower crops in the sub-WMU was reasonable, despite the drought, because of the high residual soil moisture at the time of sowing. However, these crops suffered from N deficiency as the topdressed urea was not effectively used due to lack of topsoil moisture and inability to irrigate (due to high salinity of the canal water) following urea application. Despite the lack of rain or irrigation, sunflower yield was good (~3 t ha^{-1}, provided light irrigation with saline water after N topdressing) (Fig. 4), revealing its greater drought and salt tolerance than that of maize (yield ~5.9 t ha^{-1}).

Cropping Year 3 (July 2015-June 2016) - Basurabad and Fultola

The farmers at both sites transplanted five HYV rice varieties by mid-August, and mostly used the recommended fertilizer (some farmers applied less than recommended dose) and crop management practices (BRRI 2010). A few (2-3%) fields in both WMUs were planted to traditional varieties. Most of the HYV crops were harvested in the second half of November, except for the short-duration HYV those harvested in the later part of October. Yield of HYV rice varied from 3.5-5.5 t ha^{-1} (average 5 t ha^{-1}), 1-2 t ha^{-1} higher than yield of traditional rice (Fig. 3).

In the *rabi* season, maize, sunflower, sesame and mungbean were grown in both pilot WMUs. A few farmers established maize and sunflower by dibbling into moist non-tilled soil on 17 December 2015 (Fultola) and 29 December 2015 (Basurabad), or into cultivated soil on 29 January 2016 (Fultola), and used recommended fertilizer and crop management practices (BARI, 2006). Some farmers sowed sesame and mungbean in late January 2016 at Fultola and in mid February 2016 at Basurabad, following conventional tillage, without fertilizer. The majority of farmers in the two pilot WMUs ploughed their land and sowed sesame in the third week of February 2016.

The growth and development of the dibbled maize and sunflower were very good. Establishment and growth of the farmers' sesame and mungbean crops were also moderate to good. However, waterlogging as a result of ~100 mm rains in February 2016 (Fig. 5c) severely damaged or destroyed all the *rabi* crops in polder 30, except for the early sown sunflower and maize in the pilot WMUs. Average yield of sunflower and maize was ~1.0 t ha^{-1} and 6.5 t ha^{-1}, respectively (Fig. 4). The performance sunflower was poor as the crop was waterlogged for a week at flowering. But the maize, being longer duration, recovered well and produced a reasonable yield. Despite the lower yield (than achievable) of the sunflower and maize, the farmers expressed their satisfaction as they were able to save the crops by making field channels and draining the fields. The community also recognized the importance of digging field channels and sluice gate operation, and is now convinced that drainage is necessary for successful cultivation of *rabi* crops in the polder.

Annual system productivity

Annual system productivity was calculated as rice equivalent yield (REY) based on the local market price for each crop (HYV rice Tk. 18.75, traditional rice Tk. 22.5, sunflower Tk. 33.75, maize Tk. 16.25, traditional sesame Tk. 50 per kg), as follows: REY of crop A = yield of A (kg ha^{-1}) * price of A (Tk kg^{-1})/price of HYV rice (Tk kg^{-1}). Over the three years, traditional system REY was always <3.5 t ha^{-1}, compared with $6.6^{-1}0.5$ t ha^{-1} (Table 1) using improved varieties and water management. The variability in REY of the improved systems was due to failure to fully implement the recommended cultural and water management practices. The result indicated that with recommended practice, REY in excess of 10 t ha^{-1} is achievable.

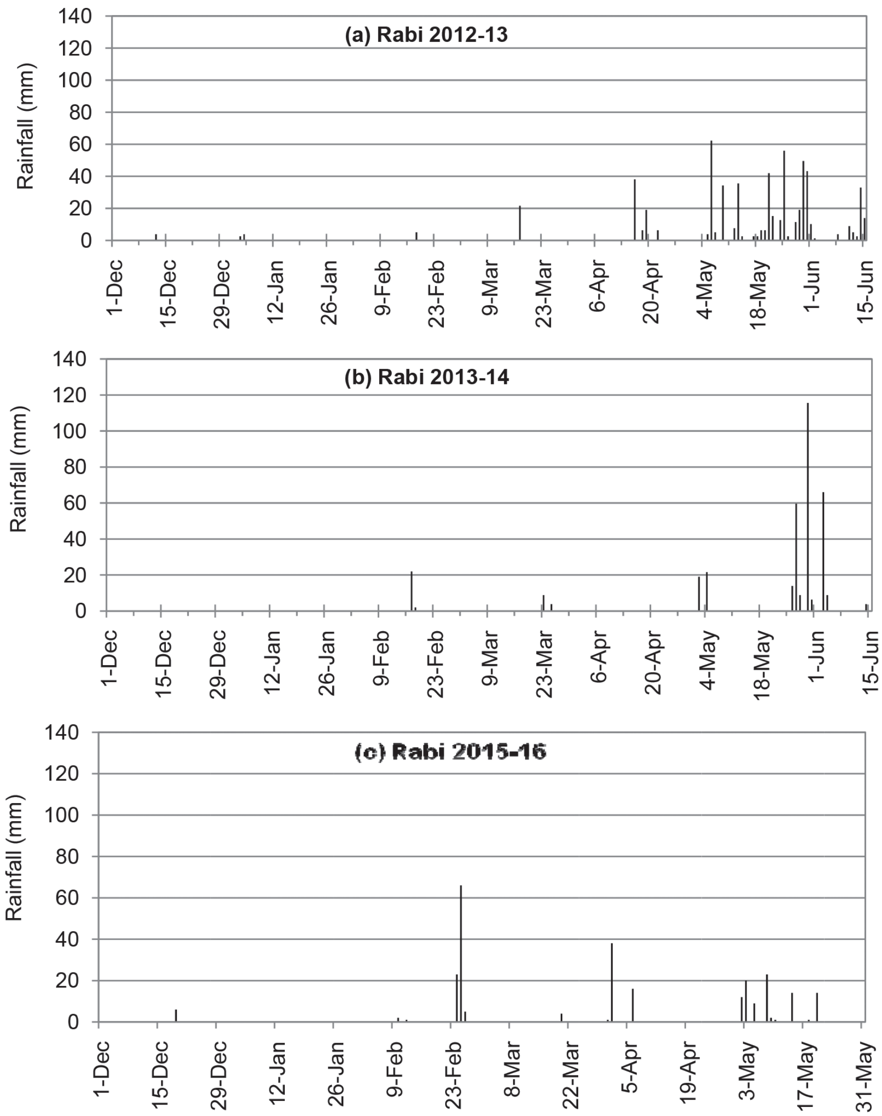

Fig. 5. Rainfall in the pilot watersheds in the rabi seasons of 2012-13 (a), 2013-14 (b) and 2015-16 (c).

Table 1. *Annual system productivity in the pilot watersheds at polder 30*

Water management	Cropping pattern	Total system rice equivalent yield (t ha^{-1} yr^{-1})			
		2012-13	2013-14	2015-16	Mean
Improved	HYV Rice - Sunflower	7.4	10.4	6.6	8.1
	HYV Rice - Maize	9.5	9.9	10.5	10.0
Traditional	Traditional Rice - Sesame	3.4	3.5	3.0	3.3

Land topography and water level elevation influencing drainage

Land elevation in the catchments of Khoria, Katakhali and Per-Batiaghata sluice gates varied from 0.41 m below mean sea level (MSL; -0.41 m MSL) to 3.00 m above MSL (+3.00 m MSL) (IRRI 2017). But most lands in three catchments (~80% of the lands) lay within +0.10 and +1.00 m MSL. Khan et al. (2015) reported that land elevation in much of Polder 30 was similar to that in the study catchments, except for two large low-lying pockets on the western side of the polder.

The water level in Kazibacha River flowing east side of Polder 30 varied from -2.02 to +2.80 m MSL during spring tides and from -1.32 to +1.90 m MSL during neap tides in the wet season from June to December 2015 (IRRI 2017). Water level fluctuations in the Lower Salta River flowing west side of the polder were slightly higher, varying from -2.16 to +3.05 m MSL and -1.44 to +1.94 m MSL during spring and neap tides, respectively. The water level elevation in the main drainage canals connected to Katakhali, Khoria, and Per-Batiaghata regulators varied from -0.79 to +0.91 m MSL.

At low tide, water level elevation in the peripheral rivers of Polder 30 was always lower than elevation of all of the lands in all three catchments, by around 0.3 to 2.2 m (IRRI 2017). This clearly indicates opportunities for gravity drainage from the agricultural lands of Polder 30 under the present tidal conditions.

Conclusions and recommendations

The results show that it is possible to triple annual productivity in a polder in a medium salinity region of the coastal zone of Bangladesh, using improved rice and *rabi* crop varieties, recommended crop management practices, and good water management, especially drainage at critical growth stages of wet season rice and following high rainfall events in both wet and dry seasons. Land topography and tidal dynamics of the peripheral rivers of the study polder indicated opportunities for gravity drainage by operating the sluice gates synchronizing with the tidal phenomenon of the river systems. Achieving this requires strong community cooperation and coordination for both water management and cropping system synchronization. The opportunity for increasing productivity in this way has not yet been recognized by the policymakers, water management and agricultural extension authorities, and millions of farming families living in the polder zone of the Bangladesh's Ganges coastal zone. Successful large-scale implementation of these opportunities requires a change in mind set and increased investment in agriculture and water management focusing on drainage of excess water from the polder area. Until the needs for community water management within small hydrological units (WMUs) and sub-polders and cropping system synchronization are addressed, farming communities in the polders of the Ganges coastal delta will not be able to adopt and benefit from the improved agricultural technologies that most of Bangladesh benefits from.

Acknowledgements

This work was supported by the CGIAR Challenge Programme on Water and Food and the CGIAR Water Land Water and Ecosystems Coordinated Research Programme. We are grateful to all collaborating farmers and the wider communities of the participating villages, especially the WMG and WMA officials of Polder 30. We are also grateful to Nasim, Asish, Zahir Amal, Swapan, Sirajul, Priyalal and Shahana for their technical support and excellent work in the field. The content of this paper was heavily drawn from the paper submitted to World Irrigation Forum 2 held on 6-12 November 2016 in Thailand.

BIBLIOGRAPHY

Bangladesh Agricultural Research Institute (BARI). (2006). Krishi Projucti Hatboi (in Bangla) 4th edition. BARI, Gazipur, Bangladesh.

Bangladesh Bureau of Statistics (BBS). (2011). Statistical year book of Bangladesh 2010. Ministry of Planning, Dhaka, Bangladesh.

Bangladesh Rice Research Institute (BRRI). (2010). Adhunik Dhaner Chas (in Bangla). BRRI, Gazipur, Bangladesh.

Hasan, M. N., Hossain, M. S., Islam, M. R. and Bari, M. A. (2013). Trends in the availability of agricultural lands in Bangladesh. National food policy capasity strengthening programme. Soil Resources Development Institute, Dhaka, Bangladesh.

International Rice Research Institute (IRRI). (2017). Community water management for improved food security, nutrition, and livelihoods in the polders of the coastal zone of Bangladesh. Project completion report submitted to the International Water management Institute (IWMI), March 2017.

Kabir, K. A., Karim, M., Shahrier, M. B., Saha, S. B., Chakraborty, S., Jharendu, P. and Phillips, M. (2014). Homestead farming systems in southwest Bangladesh: A survey. CPWF Working Paper Series.

Khan, Z. H., Kamal, F. A., Khan, N. A. A., Khan, S. H. and Khan, M. S. A. (2015). Present surface water resources of the Ganges coastal zone of Bangladesh. In: Humphreys, E., Tuong, T. P., Buisson, M. C., Pukinskis, I. and Philipps, M. (eds) Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. CGIAR Challenge Program on Water and Food (CPWF) Conference Proceedings, Colombo, Sri Lanka, pp 14-26.

Ministry of Agriculture-Food and Agriculture Organization (MoA-FAO). (2013). Master Plan for agricultural development in the southern region of Bangladesh. Prepared by the Ministry of Agriculture of the Government of Bangladesh and Food and Agriculture Organization of the United Nations, Dhaka, Bangladesh.

Mondal, M. K., Tuong, T. P., Sharifullah, A. K. M., and Sattar, M. A. (2010). Water supply and demand for dry-season rice in the coastal polders of Bangladesh. In: Hoanh, C. T., Szuster, B. W., Suan-Pheng, K., Ismail, A. M. and Noble, A.D. (eds.) Tropical Deltas and Coastal Zones: Food Production, Communities and Environment at the Land-Water Interface Comprehensive assessment of water management in agriculture series, no. 9. CABI publication, pp 264-278.

Mondal, M. K., Paul, P. L. C., Humphreys, E., Tuong, T. P., Ritu, S. P. and Rashid, M. A. (2015a). Opportunities for cropping system intensification in coastal zone of Bangladesh. In: Humphreys, E., Tuong, T.P., Buisson, M.C., Pukinskis, I. and Philipps, M. (eds). Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. CGIAR Challenge Program on Water and Food (CPWF) Conference Proceedings, Colombo, Sri Lanka, pp 449-476.

Mondal, M.,K., Humphreys, E., Tuong, T.,P., Rahman, M.,N. and Islam, M.,K. (2015b). Community water management and cropping system synchronization: The keys to unlocking the production potential of the polder ecosystems in Bangladesh. In: Humphreys, E., Tuong, T. P., Buisson, M. C., Pukinskis, I. and Philipps, M. (eds). Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. CGIAR Challenge Program on Water and Food (CPWF) Conference Proceedings, Colombo, Sri Lanka, pp 119-130.

Ritu, S. P., Mondal, M. K., Tuong, T. P., Talukdar, S. U. and Humphreys, E. (2015). An aus-aman system for increasing the productivity of a moderately saline region of the coastal zone of Bangladesh. In: Humphreys, E., Tuong, T. P., Buisson, M. C., Pukinskis, I. and Philipps, M. (eds). Revitalizing the Ganges Coastal Zone: Turning Science into Policy and Practices. CGIAR Challenge Program on Water and Food (CPWF) Conference Proceedings, Colombo, Sri Lanka, pp 361-388.

Soil Resources Development Institute (SRDI). (2010). Saline soils of Bangladesh. SRMAF project, Ministry of Agriculture, Govt. of Bangladesh. Dhaka, Bangladesh.

Tuong, T.P., Humphreys, E., Khan, Z. H., Nelson, A., Mondal, M., Buisson, M. C. and George, P. (2014). Messages from the Ganges basin development challenge: Unlocking the production potential of the polders of the coastal zone of Bangladesh through water management investment and reform. CPWF Research for Development Series 9. Available at:

https://cgspace.cgiar.org/bitstream/handle/10568/41708/CPWF%20Ganges%20basin%20messages%20Sept%2014.pdf?sequence=5. Accessed 30 Dec 2014.

Horticulture Crops for Nutrition and Livelihood Security: Opportunities and Challenges in Coastal Region

DEEPA SAMANT[1]*, V. B. S. CHAUHAN[2] and MEENU KUMARI[1]

[1]ICAR-IIHR-Central Horticultural Experiment Station, Bhubaneswar- 751 019, Odisha, India
[2]ICAR-Central Tuber Crops Research Institute, Regional Centre, Bhubaneswar- 751 01, Odisha, India

**Corresponding author:* Email: Deepa.Samant@icar.gov.in

Coastal zones, defined as the transition areas between the terrestrial and marine environments are one of the most complex, active, diverse, dynamic, productive, valuable, and fragile ecosystems on Earth, because of continuous and intimate interaction between land, ocean, and atmospheric processes. These zones are endowed with rich floral and faunal biodiversity and support an array of habitats such as coral reefs, mangroves, mudflats, estuaries, lagoons, sand dunes, and marshes. Despite covering a small area (10%) of the earth's surface, coastal areas are one of the major sites of anthropogenic activities and settlement due to fertile low land, abundant marine resources, alluring scenic beauty, water transportation, industrial development, and petroleum exploration activities. Sixty percent of the world's major cities are located in coastal areas. Globally, around 10% of people reside in low elevation coastal areas (< 10 m above mean sea level) and nearly 40% of people live within 100km of the coast.

India has the 18th longest coastline measuring about 7517km, of which 5423km covers the mainland and the remaining 2094km encircles Lakshadweep and Andaman and Nicobar Islands (Table 1). The mainland coastline touches five states (Gujarat, Maharashtra, Goa, Karnataka, and Kerala) and one union territory (Daman and Diu) on the west coast, and four states (Tamil Nadu, Andhra Pradesh, Odisha, and West Bengal) and one union territory (Puducherry) on the east coast. In general, the climate of coastal regions falls under hot and humid to sub-humid with the exception of Gujarat which has a semi-arid to an arid climate. Almost the entire coastal area in the country, excluding the north Gujarat coast, receives normal annual rainfall in excess of 1000mm (east coast: 1000-2500mm, west coast: >2500mm). Most of the coastal areas receive about 80% of the annual rainfall from June to September with the exception of Tamil Nadu which receives about 70% of rainfall during October and November. Two states on the east coast, namely, Odisha and West Bengal receive some amount of rainfall during May and October too. The average temperature on the west coast ranges from 25.0-27.5 °C. A similar temperature range is observed in the coastal region of Odisha and West Bengal. But, Tamil Nadu and Andhra Pradesh on the east coast, experience an average temperature of more than 27.5°C. Soils in coastal areas vary from alluvial to lateritic, coarse sand to clay, non-saline to saline, alkaline to acidic, well-drained to poorly drained, and have low to high organic matter content.

Indian coastal zones are densely populated. About 35% of people inhabit within 100 km of the coastline. Coastal district has a population density ranging from 46 to 2098 persons per sq. km on the mainland and from 20 to 2149 persons on Island (Table 1). Nearly 52% of the coastal districts are with high (501-1000 persons per sq. km.) to very high population density (>1000 persons per sq. km) as against the national population density (382 persons per sq. km). Agriculture is the mainstay of the coastal economy as the coastal ecosystem offers very favourable agro-climatic conditions for the cultivation of a wide range of food and non-food crops, *viz.*, paddy, sugarcane, groundnut, coconut, cashew nut, betel nut, millets, pulses, spices, fruits, vegetables, cotton, rubber, etc. due to abundant sunshine, solar and wind energy, rainfall, surface, and groundwater resources, fertile deltaic soils, and humid to sub-humid climate. However, coastal agriculture is suffering from poor productivity due to climatic aberrations (storm, cyclones, and floods), soil and water-related issues (impeded drainage, poor moisture retention, nutrient leaching, low fertility, salinity, waterlogging, acidity, scarcity of freshwater, and poor quality of water), and mismanagement and overexploitation of natural resources by humans. Agriculture in the coastal areas is predominantly rain-fed and characterized by excess water during the rainy season followed by acute water scarcity coupled with soil/water salinity in the post-monsoon period. Besides, the coastal lands are in general, mono-cropped with the low productive paddy which leads to sub-optimal resource utilization and poor return. About 90% of the farming communities in the coastal region are marginal to small with <1 ha agricultural land and are living below

Table 1. *Coastal States and Union Territories of India*

	State/Union Territory	Coastal length (km)	Coastal District	Population density (person per sq. km, Census-2011)	
Mainland	Gujarat	1214.7	Kutch, Morbi, Jamnagar, Devbhoomi Dwarka, Porbandar, Junagadh, Gir Somnath, Amreli, Bhavnagar, Ahmedabad, Anand, Bharuch, Surat, Navsari, and Valsad (15)	46 (Kutch)	1375 (Surat)
	Maharashtra	652.6	Palghar, Thane, Mumbai Suburban, Mumbai City, Raigad, Ratnagiri, and Sindhudurg (7)	163 (Sindhudurg)	20980 (Mum. Suburban)
	Goa	151.0	North Goa and South Goa (2)	326 (South Goa)	471 (North Goa)
	Karnataka	280.0	Uttar Kannada, Udupi, and Dakshin Kannada (3)	140 (U. Kannada)	430 (D. Kannada)
	Kerala	569.7	Kasaragod, Kannur, Kozhikode, Malappuram, Thrissur, Ernakulum, Alappuzha, Kollam, and Thiruvananthapuram (9)	657 (Kasaragod)	1504 (Alappuzha)
	Tamil Nadu	906.9	Thiruvallur, Chennai, Chengalpattu, Kanchipuram, Villupuram, Cuddalore, Nagapattinum, Thiruvarur, Thanjavur, Pudukkottai, Ramanathapuram, Thoothukudi, Tirunelveli, and Kanyakumari (14)	330 (Ramanathapuram)	26553 (Chennai)
	Andhra Pradesh	973.7	Srikakulam, Vizianagaram, Vishakhapatnam, East Godavari, West Godavari, Krishna, Guntur, Prakasam, and Nellore (9)	193 (Prakasam)	519 (Krishna)
	Odisha	476.4	Balasore, Bhadrak, Kendrapara, Jagatsinghpur, Puri, and Ganjam (6)	430 (Ganjam)	682 (Jagatsinghpur)
	West Bengal	157.5	North 24 Pargana, South 24 Pargana, and East Midnapore (3)	819 (S. 24 Pargana)	2245 (N. 24 Pargana)
	Puducherry	30.6	Puducherry, Yanam, Mahe, and Karaikal (4)	1275 (Karaikal)	4646 (Mahe)
	Daman & Diu	9.5	Daman and Diu (2)	1335 (Diu)	2655 (Daman)
Island	Andaman and Nicobar	1962.0	North and Middle Andaman, Nocobar, and South Andaman (3)	20 (Nocobar)	89 (S. Andaman)
	Lakshadweep	132.0	Lakshadweep (1)	2149 (Lakshadweep)	
➢ **Total length of Indian coast line: 7516.6 (5422.6km Mainland and 2094km Island)** ➢ **Total no. of coastal Districts in India: 78 (74 Mainland and 4 Island)**					

poverty line. Poverty and unemployment among the large section of farming community is the characteristic feature of coastal agriculture which leads to overexploitation of natural resources and damage to coastal ecology, affecting the agricultural productivity negatively as a whole. Because of low productivity, coastal agriculture is facing a great challenge in achieving food and nutrition security and sustaining the livelihood of poverty stricken coastal inhabitant.

Despite many constraints and adversities in coastal areas, there lies a tremendous scope for enhancing agriculture productivity through development and adoption of location and problem-specific technologies and strategies in the field of natural disaster management, soil health management, water management, crop management etc. One such strategy is diversification with the horticultural crops because the main cropping system followed in the coastal area is rice-based mono-cropping.

Opportunities for horticulture in coastal ecosystem

Horticulture which includes fruits, vegetables, ornamental plants, aromatic and medicinal plants, plantation crops, and spices is one of the most vibrant segments of Indian agriculture. The government of India realized its potential and role in shaping the Indian economy in the mid-eighties and accorded high priority for the development of this sector, particularly, since the VIII plan and beyond. Horticulture sector witnessed a major increase in area and production since 1991-92. Indian Horticulture production has touched 311.71 million MT during 2017-18 with a major contribution from vegetables (184.34 million MT) and fruits (97.36 million MT). We are the second-largest producer of fruits and vegetables in the world. Over the last decade, the area under horticulture has grown by 2.6% per annum and annual production by 4.8%. The horticulture sector is contributing around 33% to Agriculture output from 11% cropped area. Diversification with Horticulture has brought out economic prosperity in many states of India through increased productivity, employment generation, and enhanced exports. Caught up between the growing demand for food, nutrition, and livelihood security on one hand and low agricultural productivity, extreme weather events, and degradation of natural resources, on the other hand, the coastal zones of India are in great need of taking up the horticulture as one of the integral components of the coastal agriculture system on large scale. Following are some points that make horticulture a suitable choice for coastal agriculture-

Abundant of crop choices

Horticulture with diverse group of crops offers a range of crop choices to the farmers for crop diversification in coastal agriculture. Availability of moisture throughout the year with excellent soil and climatic conditions facilitates cultivation of horticultural crops. Some important ones under various crop groups are listed in Table 2 for ready reference-

Wider adaptability

Many horticultural crops are hardy and well adapted to the adverse edaphic and climatic conditions where cereals and other crops fail to produce economic yields. Most of the coastal areas have problematic soils, *viz.*, saline, alkaline, acid sulphate, marshy, and waterlogged soils. Soil salinity caused by the presence of saline groundwater at shallow depth and frequent seawater inundation in the low-lying areas, is the main factor responsible for poor agricultural productivity in coastal regions. About 3.1 Mha area along the coastal tracts of West Bengal, Odisha, Andhra Pradesh, Puducherry, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, Goa, and Andaman & Nicobar Islands are affected by the problem of salinity. Salt-affected soils of coastal land could be utilized for the cultivation of coconut, date palm, *ber*, sapota, *aonla*, *karonda*, and custard apple because of moderate to high salt tolerance ability (Table 3). Cashew can be cultivated quite successfully in sand dunes which at present are unutilized and often encroach on adjoining farmlands year after year. Cashew trees once established stabilize the soil. Coastal areas with temporary water stagnation issues could be utilized for *jamun*. Vegetables like colocasia, swamp taro, *kalmi sag* (*Ipomoea aquatic*), and *thankuni sag* (*Hydrocotyl asiatica*) can be grown in a waterlogged eco-system.

Climate suitability for cultivation of exotic crops

Climatic conditions of coastal areas are very favourable for expanding the area under exotic horticultural crops which are relatively new to India, *viz.*, rambutan, mangosteen, etc. Cultivation of rambutan and mangosteen is becoming very popular on the west coast, particularly Kerala and Karnataka.

Table 2. *Major horticulture crops of coastal India*

Sl. No.	Category	Crops
1.	Fruits	Mango, banana, sapota, guava, pineapple, ber, jack fruit, papaya, pummelo, acid lime, rough lemon, aonla, kokum, mangosteen
2.	Vegetables	Brinjal, tomato, potato, onion, okra, chilli, vegetable cowpea, amaranthus, sweet potato, yam, colocasia, cucurbits, radish, drumstick, tapioca, curry leaf, beans, bitter gourd, carrot
3.	Plantation crops	Coconut, cashew, arecanut, rubber, palmyrah palm, oil palm, cocoa, coffee
4.	Spices and condiments	Nutmeg, betelvine, black pepper, cinnamon, cardamom, clove, turmeric, ginger, chilli, Malabar tamarind, vanilla

Table 3. *Relative tolerance of fruit crops to salinity*

Tolerance level	pH	ESP (%)	ECe (dS m^{-1})	Fruit crops
High	9.9-10.5	40-50	12-15	Ber, date palm, sapota, khirni
Moderate	8.5-9.5	30-40	09-12	Aonla, ber, karonda, pomegranate, bael, wood apple, jamun, tamarind, custard apple
Low	7.5-8.5	20-30	06-09	Guava, mango
Sensitive	6.8-7.5	15-20	04-06	Banana, pineapple, Jackfruit, cashew

Better returns

Horticultural crops are high-value low volume crops and provide better returns per unit area over other crops. Fruits and vegetables give 4-10 times the return from other crop groups, namely, cereals, pulses, and oilseeds. Diversification towards horticultural crops is the most powerful factor in raising the growth rate of agriculture GDP. A one percent shift in the area from non-horticultural crops to horticultural crops adds 0.46 percentage points to the growth rate of the agriculture sector. Vegetables can be grown on small patches of land by the farmers. Vegetable cultivation provides quick returns to the farmers. Perennial horticultural crops have a long productive life and planting them once provides continuous yield for a long period of time.

Employment generation

Cultivation of horticultural crop is labour intensive activity, hence, provides assured employment opportunities to the inhabitants of the coastal region. Fruit production requires on an average 860 man-days per hectare per annum as against the employment generation of 143 man-days by cereal crops. Banana and pineapple generate much larger employment ranging from 1,000 to 2,500 man-days per hectare per annum. Various industries, *viz.*, processing, pharmaceutical, perfumery and cosmetics, chemical, confectionery, oils and paints, coir, etc. are running on the raw material provided by horticultural crops. Thus, the Horticulture sector has tremendous potential for employment generation.

Better foreign exchange

Horticultural crops fetch more foreign exchange per unit area than cereal crops due to high yields and higher prices available in the international market. Fruits earn 20-30 times more foreign exchange than cereal crops.

Better utilization of natural resources

Diverse features of horticultural crops, *viz.*, growth habit, canopy pattern, root depth, and crop duration allows scope for multi-tier cropping system, which ensures efficient utilization of natural resources (sunlight, water, land, and nutrient) and gives better returns per unit area, per unit time, and per unit input over the monocropping. The practice of multi-tier cropping system is highly successful in plantation crops such as coconut, arecanut, cashew, and coffee. Some examples of multi-tier cropping systems are -coconut/arecanut + black pepper + cocoa + pineapple, coconut/arecanut + black pepper+ banana + ginger+ pineapple, coconut + black pepper + nutmeg + banana + pineapple, areca nut + banana + turmeric, coconut +black pepper + pineapple, coconut + cocoa +coffee + pineapple, mango + pineapple etc. Elephant foot yam, tapioca, greater yam, and sweet potato are common inter-crops in humid tropics. Multi-tier cropping system is a boon to the farming community because of efficient utilization of natural resources, enhancement in productivity of main crop (15-20%), and high revenue realization per unit area (50-90%). This novel approach of "An inch of land with a bunch of crops" is emerging as the sustainable livelihood model for small and marginal farmers because it ensures ecological stability, enhanced soil buffering ability, continuous income, round the year employment, effective biomass recycling, and less risk of crop failure. Farmers could get a net income of about ₹ 3,75,000/- per hectare per annum by intercropping cocoa with coconut.

Change in dietary habit of people

The food preference and the consumption pattern of Indians are shifting towards fruits and vegetables from a cereal-based diet in the wake of urbanization, growing income, and health awareness. Studies on food demand indicate that a 1% increase in per capita expenditure results in a 1.9 and 1.02% increase in demand for fruits and vegetables. Thus, the per capita intake of fruits and vegetables in the country is expected to keep on increasing in the coming years. It is projected that India needs to produce 350 million MT vegetables and 125 million MT fruits by 2030 to meet the demand of the growing population. India's import of fruits is rising by 20% per year. Thus, the prospects of fruits and vegetables are very bright on the demand side.

Horticulture Vis-a-Vis nutritional and livelihood security

Horticultural crops, particularly, fruits and vegetables are not only the source of vitamins, minerals, fat, proteins, carbohydrates, and dietary fibers, but eating them reduces the risk of diseases. Low intake of fruits and vegetables has been recognized as a top risk factor for global mortality by the World Health Organization. The people in the coastal agriculture system suffer significant micronutrient and protein deficiencies because of imbalanced dietary habits. Rice is the staple food of coastal inhabitants of India, which lacks in various minerals and vitamins. Therefore, the cultivation of these protective foods assumes great importance for the nutritional security of the people. It is important to consume a variety of fruits, vegetables, spices, and condiments to derive the required nutrition because no single fruit or vegetable can nourish the body with all the vital ingredients. In India, the per capita consumption of fruits and vegetables is only about 120 and 250 g day^{-1} $person^{-1}$, which is less than the minimum dietary requirement of 200 and 300g $day^{-1}person^{-1}$. This warrants the need for scaling up the horticultural production in the country.

Several fruits with high nutrient density are considered to be super-foods, *viz.*, coconut, banana, guava, papaya, etc. Fruits and vegetables contain a number of bioactive compounds or phytochemicals (ascorbic acid, carotenoids, tocopherols, and phenolic compounds) enabling them to act in our body as anti-oxidant, anti-allergenic, anti-carcinogenic, anti-inflammatory, etc. Under the instances of lower production of antioxidants, the human body becomes more dependent on food sources for antioxidants. For these conditions, nutraceutical rich vegetable crops like red and black carrot, beet root, pumpkin, tomato, etc. are more beneficial for health. Green leafy vegetables are a rich source of calcium, iron, alpha-carotene, ascorbic acid, riboflavin, thiamin, niacin, and folic acid. The root and tuber vegetable crops like sweet potato, taro, elephant foot yam, yam bean, etc. are rich in carbohydrates and energy. Cooked yams have about 2% protein, Cassava and sweet potato provide ascorbic acid, whereas, cereal-based foods have none. Sweet potato also contains important amino acids while rice is deficient in lysine. Roots and green tops of sweet potato (orange and yellow-fleshed type) are rich in vitamin A. Besides, sweet potato is rich in anti-oxidant and nutrients (β-carotene, ascorbic acid, and tocopherol) which can prevent coronary disorder and cancer. The comparative proximate composition of various tuber crops with rice is given in Table 4.

Peas and beans are known for the richness of proteins. Chilli, brinjal, tomato, okra, cowpea, etc. not only add diversity to the diet but also provide a lot of vitamins, minerals, and fiber-rich food. The nutritional benefits of dietary fiber are well established for reducing the risk of cancer and for lowering blood cholesterol. Cruciferous vegetables are enriched with glucosinolate components which inactivate the carcinogens by reducing their reactivity with endogenous ligands and thereby facilitating their elimination from the body. Natural pigments from vegetable crops *e.g.* black carrots, beet root and coloured hybrids of radish have the potential to be used as the source of nutraceutical to address the number of ailments and chronic diseases and also to restore the wellness of the body after diseases. Fruits and vegetable therapy is now a practice to have good health without medication and many crops are used as herbal medicine. The fruits (*aonla*, *bael*, *jamun*, *papaya*), vegetables (carrot, cauliflower, onion, garlic, leafy vegetables), spices (ginger, turmeric, black pepper, fenugreek, carom seeds), and ornamental plants (ashoka, ficus, catharanthus) protects against various kinds of diseases. The spices like turmeric, chilli, and cumin in the diet have been recognized to protect against cancer. Noni (*Morinda citrifolia*) with unique characteristics is recognized as best for health care, as it provides protection against various diseases including HIV.

Horticultural crops provide a viable option for ensuring the livelihood security of coastal farmers. The economic returns per unit area are high in horticultural crops when compared to field crops. Being labour intensive these high-value low volume crops ensure year-round employment to the entire family. Small scale cultivation or homestead gardening of fruit, vegetable, flower, medicinal and aromatic plant crops, nursery raising, orchard maintenance,

Table 4. *Comparative proximate composition of tuber crops*

Tuber crops	Grams per 100 g on dry weight basis					
	Protein	Fat	Minerals	Fiber	Carbohydrates	Calories
Potato	7.3	0.4	2.4	1.6	89.0	382
Sweet potato	3.8	0.9	3.1	2.5	88.5	377
Cassava	1.7	4.9	2.5	1.5	84.9	386
Yam	4.7	0.3	5.3	3.3	86.6	370
Colocasia	11.6	0.4	6.3	3.7	78.5	361
Elephant foot yam	5.6	0.5	3.8	3.8	86.3	371
Colocasia leaves (black type)	31.9	9.4	11.8	8.5	38.0	362
Colocasia leaves (green type)	22.6	8.7	12.8	16.8	39.4	325
Rice	7.8	0.8	0.7	0.2	89.9	397

employment in agro-chemical industries, small scale processing, marketing of fresh fruits and vegetables and processed products are various alternatives for livelihood security of coastal farmers.

Challenges for horticulture sector in coastal ecosystem

The coastal ecosystem of the country, especially the east coast, is vulnerable to natural disasters. Tropical cyclones are considered as the major natural disasters in eastern coastal regions of India owing to their intensity of damage to lives, crops, and properties. The region is highly vulnerable to cyclones as 5-6 tropical cyclones originate in the Bay of Bengal every year during April–May, and October–November, and of which about two may reach to severe stage. According to the Indian Meteorological Department (IMD), Fani was considered as the most severe storm witnessed in Odisha after Super Cyclone occurred in 1999. It made landfall near puri on 3rd May 2019 with an extremely high wind speed of >200km hr^{-1} and caused devastation in coastal districts such as Puri, Khordha, Cuttack, Jagatsinghpur, Kendrapara, and part of Dhenkanal. The perennial fruit crop plantation (mango, sapota, aonla, jackfruit, guava, pineapple, dragon fruit, and minor fruits) at ICAR-IIHR- Central Horticultural Experiment Station, Bhubaneswar got severely damaged by this cyclone. More than 75% of plants were damaged of which 41% got severely damaged with a low probability of restoration. Sapota plants were severely damaged (100%) followed by *aonla* (65%), jackfruit (54%), mango (45%), pineapple, dragon fruit, and minor fruits. It was observed that the intensity of damage was substantially low (≤10%) under high-density plantation. Station suffered a huge loss of horticultural produce (>125 tonnes). In 2018, the coastal district of Andhra Pradesh was hit by Cyclone Titli on 11th October. This cyclone resulted in severe damage to coconut and other field crops. The state reported huge damage for horticultural crops (₹ 1000 crores).

Despite having a high yield potential, horticultural crops suffer a major setback in the yield in coastal areas as compared to inland due to various constraints of coastal soil, *viz.*, excess accumulation of soluble salts and alkalinity in soil, pre-dominance of acid sulphate soils, toxicity and deficiency of nutrients in soils, the intrusion of seawater into coastal aquifers, high depth to underground water table rich in salts, periodic inundation of soil surface by the tidal water, heavy soil texture, and poor infiltration, nutrient imbalance, and erosion and sedimentation of soil. Though annual precipitation in coastal areas is very high, but it is unevenly distributed mostly concentrated in only one or two seasons, with drought-like situations for the rest of the year which takes the toll on realizing the high yield potential of horticultural crops in the region.

The climate in the coastal zone is very congenial for the attack of various insect pests and diseases limiting the production and productivity of horticultural crops. Tubers of yams and aroids on storage for the long term are often severely infested by sucking pests, particularly mealy bug which deteriorates the quality (appearance and palatability) and marketability of tubers. In coastal Odisha, mango suffers major losses due to powdery mildew (50-54 % severity in var. Banganpalli). Maturing fruit is affected by diseases like scab, bacterial canker, pre-harvest anthracnose, and sooty blotch flyspeck complex and disorder jelly seed directly affecting the fruit quality. In heavy rainfall areas of Karnataka and Kerala, arecanut is affected by a lethal disease called Koleroga/ bud rot. High humidity coupled with high temperature easily attracts wilt (fungal or bacterial) and several insect-pests in vegetable crops. Some of them are frequently known as carriers of viral diseases like jassids, whitefly, aphids, etc. In fact, coastal areas are a hot spot for viral diseases. In coastal areas, okra cultivation is severely hampered by the Yellow Vein Mosaic virus disease which is transmitted by whiteflies. In the wake of climate change, the productivity of coastal horticulture is getting badly affected by the sudden surge in non-native/alien invasive crop pests such as Coconut eriophyid mite, rugose spiralling whitefly (*Aleurodicus rugioperculatus*). Coconut yield in Odisha dwindled alarmingly after the event of Super cyclone in 1999 due to the attack of eriophyid mite. Rugose spiralling whitefly, which was reported from Pollachi (Tamil Nadu) and Palakkad (Kerala) during July-August 2016, has become a serious threat to coconut plantation in Tamil Nadu, Kerala, Karnataka, and Andhra Pradesh. Now it is blighting the coconut plantation in Odisha (2020). The prolonged dry spell during June to September and deficit rainfall coupled with decreased relative humidity could have favoured the spread of the pest in coconut plantations. This insect pest is attacking other host plants also, *viz.*, banana, mango, and guava.

Farmers of coastal regions are losing interest in agricultural activities due to the phenomenon of increased urbanization and industrialization, enhanced importance of other new sectors like information technology, alternative commercial livelihood activities such as tourism and mining. Agriculture is being felt as a sector of lesser economic importance. As a consequence, the number of people involved in agriculture is declining steadily and so is the investment in agriculture. Besides, the cost of scarce labour is increasing which in turn reducing the profit from agriculture. Concurrently, a reduction in the availability of labour for agriculture has made the timely execution of agriculture operations difficult. This is also leading to fertile agricultural lands becoming not only fallow but are getting converted into non-agricultural activities like commercial building infrastructures.

In addition to these, there are various other factors which are creating hindrance in the way of tapping the high yield potential of horticultural crops in the coastal regions of India. Some of them are given below-

- High capital investment in establishing an orchard.
- Poor capacity of farmers to invest and inadequate credit support to farmers.
- Long pre-bearing period in case of perennial horticultural crops.
- Unawareness about the improved horticultural technologies due to inadequate transfer of technology.
- High price fluctuation makes cultivation of horticultural crops challenging, especially for capital-starved marginal farmers.
- Predominance of old and senile orchards.
- Majority of farm holdings are small, fragmented and rain-fed.
- Unavailability of adequate quality planting material.
- Unavailability of suitable rootstocks for cultivation of horticultural crops in marginal and problematic soils.
- High risk of transmission of virus diseases from one generation to other in case of vegetative propagated horticultural crops.
- Poor post-harvest management poor infrastructural facilities for handling, storing, transporting, and processing the horticultural produce.
- Inadequate quality standards for horticultural produce.

Despite numerous challenges, the coastal ecosystem of the country has witnessed a significant increase in area under several key horticultural crops, which indicates the tremendous scope for horticulture in the region. With a diverse group of crops, this sector not only provides ample choices of crops for varying soil and climatic conditions, but also gives better returns per unit area as compared to other agricultural crops such as cereals. The labour intensive nature of horticulture ensures livelihood security by providing assured employment opportunities to farmers. Further, consumption of horticultural crops takes care of their nutritional requirement as these crops are filled with the goodness of vitamins, minerals, dietary fiber, and antioxidants. The yield gap between inland and coastal horticulture can be narrow dawn by developing location-specific technologies covering various aspects of crop production (quality planting material, crop management, crop protection, input/resource management, biotic and abiotic stress-tolerant varieties and rootstock, post-harvest management) and by strengthening the farmer through devising market linkages and transferring the improved technical know-how and crop advisory on a regular basis. Thus, diversification with horticulture is surely going to play a key role in bringing prosperity to the coastal region of India.

BIBLIOGRAPHY

Bandyopadhyay, B. K., Burman, D. and Mandal, S. (2011). Improving agricultural productivity in degraded coastal land of India– Experiences gained and lessons learned. *Journal of the Indian Society of Coastal Agricultural Research* **29(1):** 1-9.

Banyal, R., Sanwal, S. K., Sharma, P. C., Yadav, R. K. and Dagar, J. C. (2019). Fruit and vegetable-based saline agricultural system for nutritional and livelihood security. In: Research Developments in Saline Agriculture, Dagar, J. C., Yadav, R. K. and Sharma, P. C. (eds.), Springer Nature Singapore Pte Ltd. pp 729-751.

Bradbury, J. H. and Holloway, W. D. (1988). Chemistry of tropical root crops: Significance for nutrition and agriculture in the Pacific. Australian Centre for International Agricultural Research (ACIAR). Monograph series number 6. Canbera, Australia: ACIAR.

https://iihr.res.in/impact-analysis-cyclone-%E2%80%98fani%E2%80%99-fruit-crops-and-their-restoration-ches-bhubaneswar

Kompiang, I. P., Sinurat, A. P., Supriyati, P. T. and Darma, J. (1994). Nutritive value of protein enriched cassava: Cassapro. *Ilmu dan Peternakan*, **7(2):** 22-25.

Neumann, B., Vafeidis, A. T., Zimmermann, J. and Nicholls, R. J. (2015). Future coastal population growth and exposure to sea-level rise and coastal flooding- a global assessment. *PLOS ONE* **10(3):** e0118571.

Nimbolkar P. K., Awchare, C., Chander, S. and Hussain, F. (2016). Multi storied cropping system in horticulture- A sustainable land use approach. *International Journal of Agricultural Science* **8(55):** 3016-3019.

Pathak, S. and Saroj, P. L. (1999). Using participatory approaches for rehabilitating salt affected lands by fruit based agroforestry systems. *Indian Journal of Soil Conservation* **27(3):** 220-226.

Rajkumar, Singh, A., Yadav, R.K. (2016). Nursery management in fruit crops in salt-affected soils. In: Quality seed production, processing and certification of selected field and vegetable crops in salt affected areas. Training manual, ICAR-CSSRI, Karnal, pp 125-131.

Rani, S., Maheswarappa, H. P. and Sumitha, S. (2018). Coconut + cocoa + nutmeg cropping system at the foot hills of Western Ghats- success story. *Indian coconut Journal* **LXI(6):** 14-15.

Sabareshwari, V. and Ramya, A. (2018). Coastal saline soils of India: A review. *Agricultural Reviews* **39(1):** 86-88.

Sahoo, N., Roy Chowdhury, S. R. Brahamanand, P. S., Mohanty, Rajeeb K., Jena, S. K., Thakur, A. K., James, B. K. and Kumar Ashwani (2006). Integrated management approaches for water logged ecosystem research. Research Bulletin No. 30, Water Technology Centre for Eastern Region (ICAR), Bhubaneswar, Orissa, India.

Sen, H. S., Sahoo, N., Sinhababu, D. P., Saha, S. and Behera, K. S. (2011). Improving agricultural productivity through diversified farming and enhancing livelihood security in coastal ecosystem with special reference to India. *Oryza,* **48(1):** 1-21.

Singh, H. P. and Malhotra, S. K. (2011). Horticulture for food, nutrition, health care and livelihood security. Key note lecture in International Consortium of Contemporary Biologists, 4th International Conference on Life Science Research for Rural and Agricultural Development, December 27-29, 2011, Central Potato Research Station, Patna, India. pp 1-20. www.iomesvis.in

Yadav J. S. P., Bandopadhyay, A. K. and Bandopadhyay, B. K. (1983). Extent of coastal saline soils of India. *Journal of the Indian Society of Coastal Agricultural Research* **1(1):** 1-6.

Integrated Farming Systems for Enhancing Productivity and Climate Resilience for Coastal Region

C. JAYANTHI*

Former Director (Crop Management), TNAU
49-50, Aishwarya Nagar, P.N.Pudur, Coimbatore - 641 041

**Corresponding author:* Email: jayanthichins@hotmail.com

In India, majority of the farmers are small and marginal, often working on landholdings that are less than one hectare or between one and two hectares. Nearly 57.8 percent of India's rural households are engaged in agriculture. Of them, over 69 percent possess or work on marginal landholdings, and 17.1 percent, on small landholdings. About 72.3 percent of India's rural households work as either cultivators or agricultural labourers in the agriculture sector as per the latest census of 2011. However, the share of cultivators employed in the agriculture sector has declined from 71.9 percent in 1951 to 45.1 percent in 2011, owing to low productivity, which, in turn, is the result of various factors including adverse weather conditions. The lack of agricultural growth has pushed the rural populations towards the non-farm sector, increasing non-farm rural employment by about 12 percent between 1999-2000 and 2011-2012. Indeed, the non-farm sector has emerged as a residual sector for people who find agriculture to be risky and lacking in remuneration.

Past strategy for development of the agriculture sector in India has focused primarily on raising agricultural output and improving food security. During the last half a century (1965 to 2015), since the adoption of green revolution, India's food production multiplied 3.7 times, while population multiplied by 2.55 times. The net result has been a 45 per cent increase in per person food production, which has made India not only sufficient at aggregate level, but also a net food exporting country. The NSSO data on Consumption Expenditure Survey for year 2011-12 reveals that more than one fifth of rural households with self-employment in agriculture as their principle occupation were having income less than the poverty line. Low level of absolute income as well as large and deteriorating disparity between income of a farmer and non-agricultural worker constitute an important reason for the emergence of agrarian distress in the country during 1990's. The country also witnessed a sharp increase in farmer's suicide during 1995 to 2007, losses from farming shocks in farm income and low farm income. It is apparent that income earned by a farmer from agriculture is crucial to address agrarian distress and promote farmers welfare.

With this background, Integrated Farming Systems (IFS) therefore assumes greater importance for sound management of farm resources to enhance the farm productivity and reduce the environmental degradation, improve the quality of life of resource poor farmers and maintain sustainability. In order to sustain a positive growth rate in agriculture, a holistic approach is the need of the hour. Farming system is a mix of farm enterprises in which farm families allocate resources for efficient utilization of the existing enterprises for enhancing productivity and profitability of the farm. As early as 1977, FAO has stated that "in Integrated Farming System there is no waste" and "waste is only a misplaced resource which can become a valuable material for another product".

Major farming systems in India are classified into eight broad categories viz., irrigated, wetland, rainfed farming in humid, dry and cold areas, coastal, mixed and urban based farming systems. India, being the country of rich agricultural diversity, almost all the farming systems are under practice across various agro-ecosystems.

Successful IFS in Tamil Nadu

Modules for lowland, irrigated dryland & rainfed ecosystems

Studies on integrated farming system involving various components were carried out at different agro-climatic zones of India since 1985. The approaches were to find out viable components for wetland, irrigated dryland and rainfed situations. The identified technologies emanated from the research programmes on integrated farming systems for

Table 1. *Promising IFS Technologies developed and adopted by farmers in Tamil Nadu*

Ecosystem	Farming system technology
Lowland (1ha)	i. Cropping (0.75 ha) + fodder Crop (0.12 ha) + fishery (1000 nos.) + mushroom (5 kg/day) + goat (20 female + 1 male) + vermicompost (4t production Capacity) ii. Crops (80 % area) + fishery - 500 No's (10 Cents) + poultry-50 birds (layer/ broiler) + mushroom (5 kg/day) + vermicompost with 5 t production capacity
Irrigated dryland (1ha)	i. Cropping (0.70 ha) + milch cows (3 + 2) + goat (10 female + 1 male) + vegetables (0.06 ha) + fodder Crop (0.20 ha) + vermicompost (6 t production capacity) ii. Cropping (90% area) + milch cows (2 Nos.) + biogas unit (2 m^3) + Desi poultry - 30 birds + goat (10 + 1 No's)
Rainfed (1ha)	i. Cropping (0.75 ha) + silvipasture (0.20 ha) + farm pond (0.04 ha) + buffalo (2 Nos.) + goat (10+1) + bio-compost (8 t production capacity) ii. Cropping and horti-pasture (90 % area) + sheep (10 + 1) + desi poultry - 30 birds + vermicompost + mobile sprinkler (1 unit) + farm pond (10 cents)

the last three decades are enormous (Table 1). The best combinations of crop based integrated farming system which plays a crucial role in livelihood security are discussed below.

Lowland ecosystem

To enhance and sustain the productivity, economic returns, employment generation for family labour, efficient resource recycling and improving the soil fertility with environmental protection, integration of cropping with 0.25 ha each of sugarcane (planted)-sugarcane (ratoon) -banana (3 years), banana-turmeric-rice-banana (3 years), and annual cropping of maize-rice-sesame-sun hemp rotation applied with recycled goat manure as fish pond silt @ 6.25 t/ha and 100 per cent recommended NPK fertilizer for each crop combined with BN hybrid grass + desmanthus in 0.10 ha for 20 female + one male Tellicherry goat and 400 numbers of polyculture fish in 0.04 ha pond water comprising catla (20 per cent), silver carp (20 per cent), rohu (20 per cent), mirgal (15 per cent), common carp (15 per cent) and grass carp (10 per cent) fed with goat dropping could be resorted. The system as a whole recorded 37679 kg/ha of RGEY (Rice grain equivalent yield), ₹1,31,118 of net return per hectare with benefit cost ratio of 3.36, employment generation of 576 mandays and nutrient gained by recycling of goat manure was 20.2, 21.0 and 15.9 kg N, P_2O_5 and K_2O through fish pond silt (Jayanthi, *et.al.*,2009).

The model comprising of cropping systems (Rice – Rice – Blackgram, Maize – Rice – Sesame, Bhendi-Rice – Sunflower, CO 4 Fodder grass, Azolla in 0.6 ha + Horticulture (Banana) in 0.1 ha + Dairy (2 cow + 1 heifer) + Fisheries (0.08 ha) + Poultry (0.01) + Vermicompost developed for the marginal farmers (Fig. 1) of cauvery delta zone, gave the production throughout the year (25.37 t REY/year), Gross income (₹3.94 lakhs peryear), net income (₹1.76 lakhs per year) and generate employment (414 man days per year). The highest net return of ₹79719 was realized from cropping component followed by the dairy (₹28813), fisheries (₹27624), poultry (₹16354) and horticulture (₹13177). The IFS model provides employment and profit throughout the year. The model also meets 27.6% of inputs required for different enterprises within the components besides providing all the commodities (Cereal, pulses, oilseeds, vegetables, fruit, chicken, milk and fish) required for the farm family (AICRP – IFS Annual report – TNAU - 2016).

Irrigated dryland ecosystem

Farmer participatory research for irrigated dryland revealed that to enhance and sustain the productivity, economic returns, employment generation for family labour and soil fertility with environmental protection for one acre land, integration of sunflower - maize + cowpea - green gram in 0.60 ac with 2.6 t composted organic manure (50% of production) to sunflower + 100% recommended NPK fertilizer to each crop in the system and 0.9 t composted organic manure (50% of the production) along with 100% recommended NPK fertilizer to CO 3 cumbu-napier

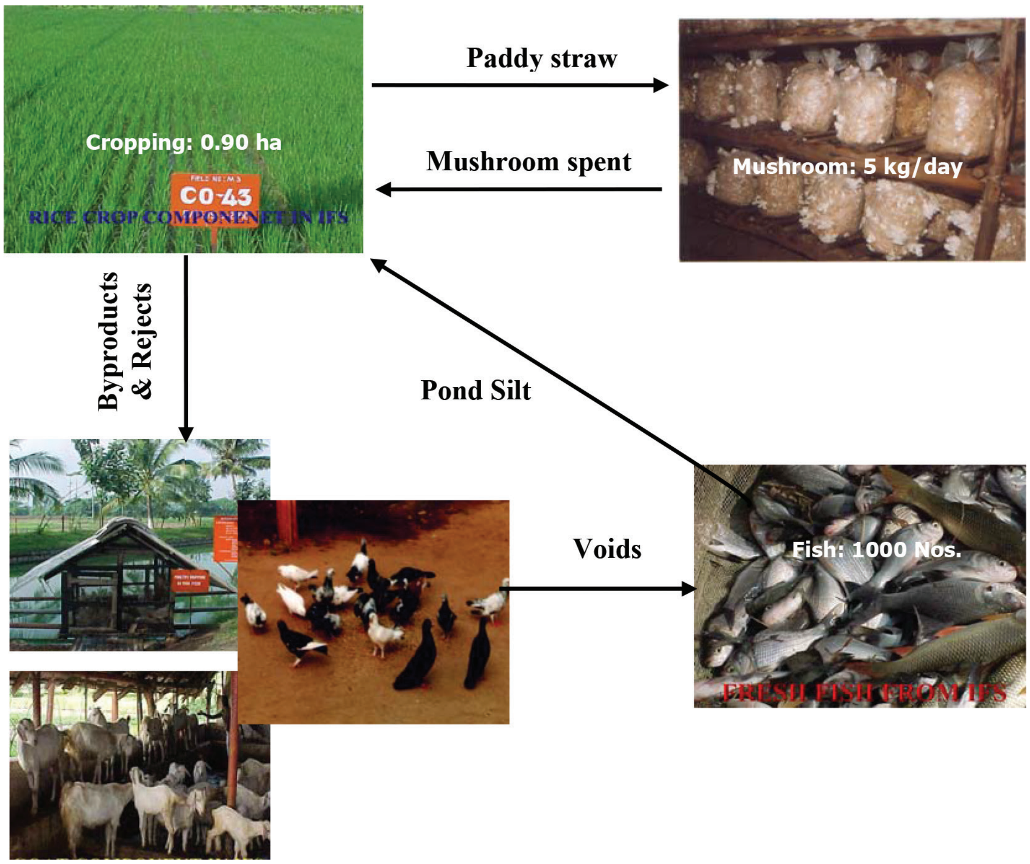

Fig. 1. Component integration and resource recycling in lowland ecosystem

hybrid grass + Desmanthus 3:1 ratio in 0.20 ac and for vegetable crop raised in 0.10 ac, 0.5 t vermicompost application along with 150% recommended NPK fertilizer + milch cow (2+1) + Tellicherry goat (10 female + one male) + guinea fowl (20 Nos.) could be resorted (Jayanthi, *et al.*, 2009).

IFS model developed for 1.20 ha by AICRP – IFS, TNAU, Coimbatore with components crop – horticulture – dairy - goat rearing – biogas – vermicompost – border plants and kitchen garden, a net return of ₹2,92,702 / year could be realized (Fig. 2). Cropping component recorded a maximum net return of ₹94,586 followed by dairy and goat unit with net returns of ₹91,588 and ₹66,389 respectively. The net returns from other enterprises like vermicompost unit, biogas unit, compost yard, border plants and kitchen garden was ₹39,955. Saving of production cost, with recycled farm products was 27.6 % (₹1,12,573) and farm labour engaged was 35.9 % (₹1,46,531). The average total farm production per year in terms of maize equivalent yield from main product was 38.2 t/ha and from by product was 7.7 t/ha summing to a total of 46 t. The model generated a mean employment of 778 man days round the year with a benefit cost ratio of 1.96. The nutrient addition through vermicompost and FYM was 191 kg nitrogen, 86 kg phosphorus and 112 kg potassium per year (AICRP – IFS Annual report – TNAU - 2016).

This integrated farming system of irrigated dryland ecosystem assures the climate resilient agriculture in areas with ground water potential.

Rainfed ecosystem

On-farm experiments were conducted to optimize and stabilize the crop - livestock - silvipastoral farming system in dry land areas of Western zone of Tamil Nadu.

Research revealed that, rotational grazing of 39 numbers of sheep per ha is optimum stocking density to graze in

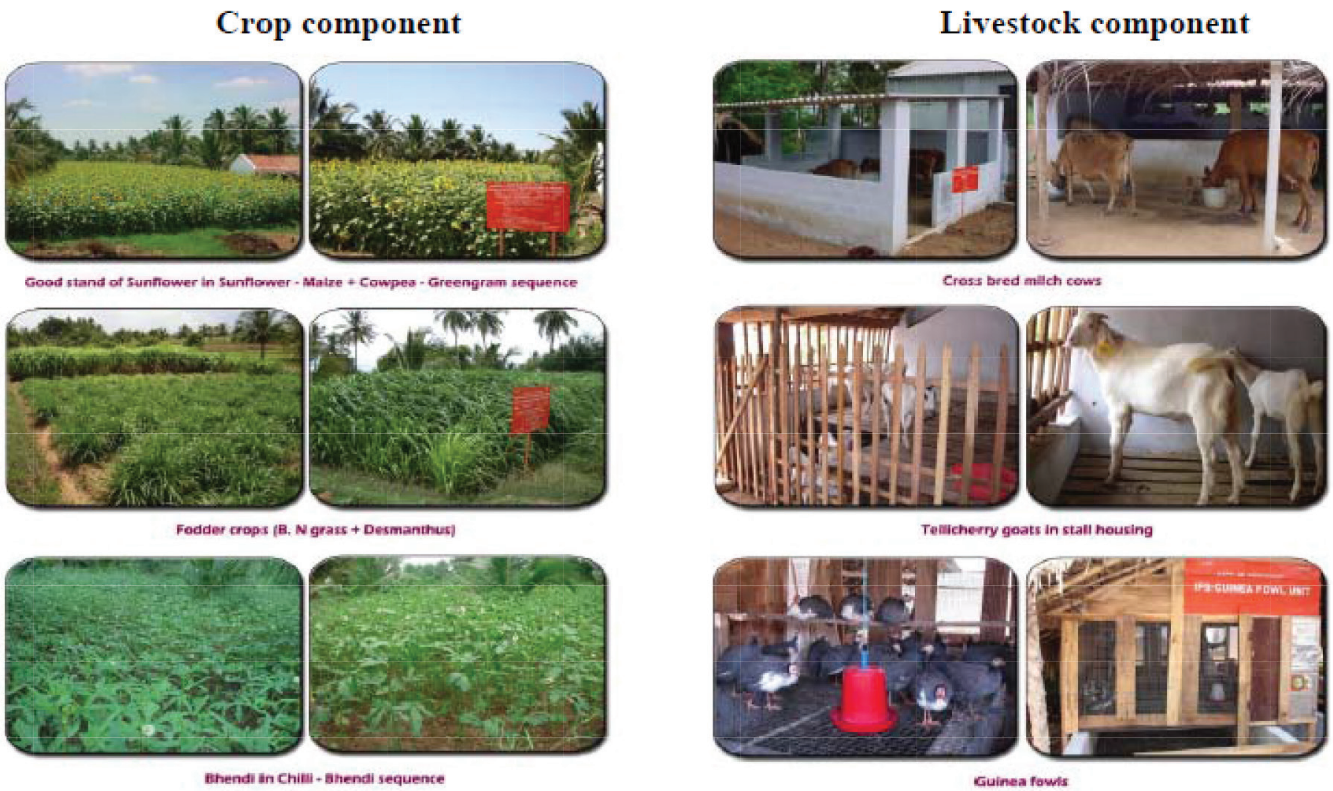

Fig. 2. Farmer Participatory Farming System for Irrigated Upland

the silvipasture land with *Cenchrus setigeru*, *Stylosanthes hamata*, fodder sorghum and *Pillipesara* fodder system. *Cenchrus setigerus*, *S. hamata*, fodder sorghum and *Pillipesara* system with sheep (5+1) and buffalo (2 nos) was the best promising IFS, which generated the highest system productivity, employment generation, net return and benefit cost (Jayanthi, 2013) (Fig. 3).

Successful IFS in Uttar Pradesh

Farming system models were developed through integration of livestock, poultry and fishery components with crop production, which established mutual beneficial relationship facilitating effective recycling of residues within the system.

An area of 0.5 ha area was allocated to rice - pea - okra sequence and in small area of the farm, the fodder sequence involving sorghum - berseem - maize was taken to meet the green fodder requirement of dairy throughout the year and hence these two cropping sequences were integrated with different farming system enterprises like dairy, poultry and fishery to find out the best combination of farming system components. The farming system component consisting of crop +dairy + poultry + fishery resulted in the highest system productivity of 1,17,846 kg ha^{-1} and net income of ₹ 4,07,737/-ha^{-1} than crop + dairy, crop + poultry, crop + fish, crop + dairy + poultry, crop + dairy + fish, crop + fish + poultry (Kalyan Singh *et al.*, 2006).

Successful IFS in Maharastra

A field experiment was conducted at Parbhani for three years to compare comparative productivity and profitability of sole cropping, cropping + one cross bred cow and cropping + one cross bred cow + sericulture. The land area allotted to each treatment was 0.40 ha. Mulberry was planted on 0.10 ha. The three years result indicated that maximum annual net income was obtained from cropping + dairy. However, maximum employment was generated in cropping + dairy + sericulture.

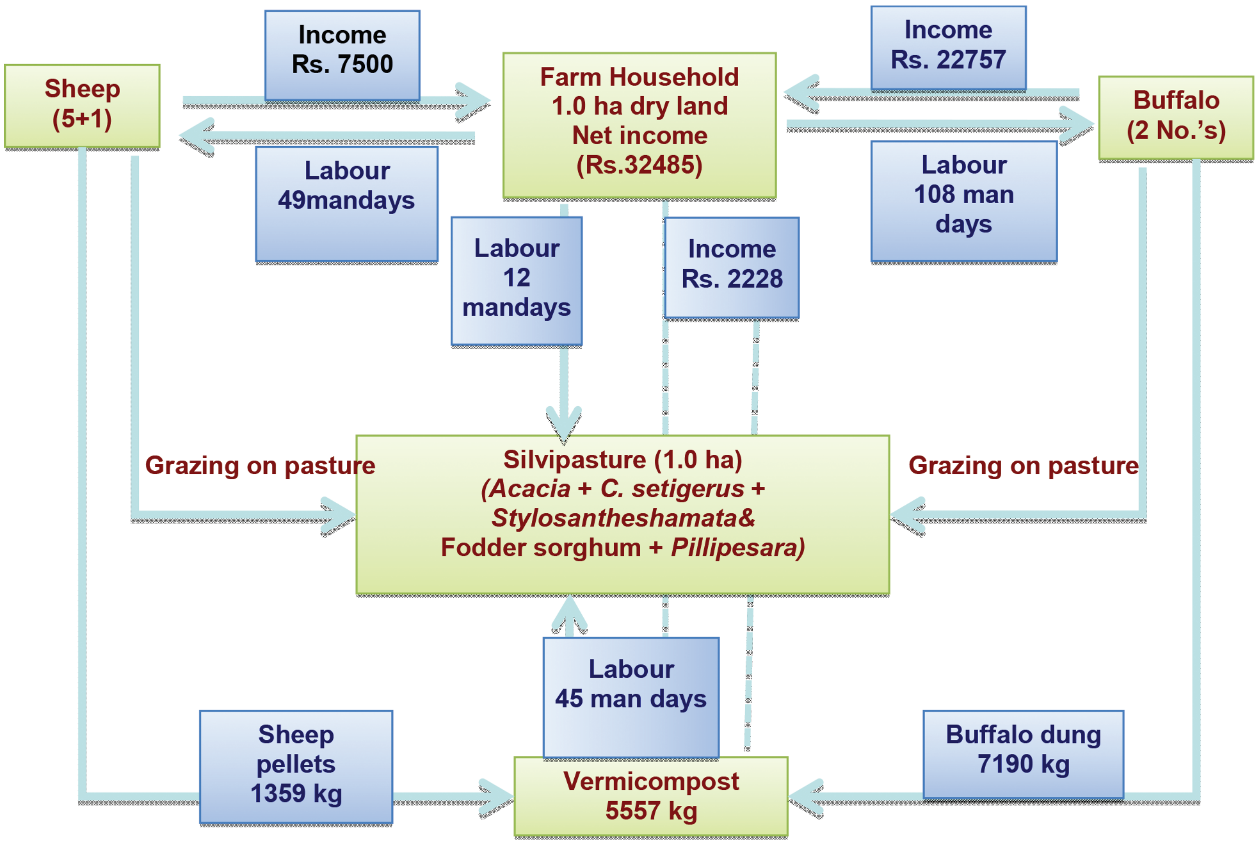

Fig. 3. Resource flow in Fodder + Buffalo + Sheep + Vermicompostsilvipastoral farming system (ha)

IFS modules for coastal agriculture

a. Fish cum duck farming: Fish – duck combination, in fact is viewed as a means of reducing the cost of feed for ducks and as a convenient and inexpensive way of fertilizing ponds for production of fish. Dabbling habits of duck accelerates the recycling of nutrients and also oxygenate the water. Generally 8-12 week old ducklings are kept on the pond after getting them properly vaccinated. Indian runner and khaki Campbell are generally considered for integration. Normally 200-300 nos. are needed for 1.0 ha area.

b. Fish cum pig farming: Integration reduce the fish feed by 35%, pig sites are built sloping alongside the embankments so that the wastes and washing are drained directly into the pond. Two crops of pigs of 6 months duration rose along with one crop of fish. Around 30 to 40 pigs are reared to meet the requirements of fish feed and fertilizer for 1.0 ha area.

c. Fish cum rabbit rearing: About 300-400 rabbit is sufficient to fertilize 1.0 ha pond

d. Fish cum horticulture: Embankment of pond area provides more than 200 m^2, sufficient to produce fruits / vegetables (Banana, coconut and papaya) for 4-5 members in a family.

e. Cropping + dairy + silviculture (Casuarina plantation as it is salt tolerant and establish well in sandy soils)

f. Agroforestry: Wind forest belt production moderating the effect of cyclones. To tolerate the salinity and moisture stress casuarina plantation is the apt choice at spacing 10 m along the coastal line and in the inner areas cashew tree cultivations interspaced with the coconut plantation. Other trees and grasses for coastal saline regions are detailed below.

   - *Salvodera persica*, *S. leoides*, *Atriplex nummalaria*, *Juncus rigidus* for saline coastal region.

- *Simmondsia chinensis*, *Simaroba spp*. *Prosopis sp*. for the sand dune areas.
- Grass species: *Panicum maximum*, *Cenchrus*, *Chloris sp*. *Spinifex squamosus*, *Sporobolu ssp*. *Cynodon dactylon*

g. IFS for Andaman and Nicobar islands

- Coconut, fodder and milch cattle: Hybrid napier alone or with leguminous fodder like *Stylosanthus* which can support 4-5 dairy animals. Cattle manure can be recycled to the coconut garden.
- Coconut, fodder, fish and prawn culture: It is proposed for the marshy areas. Coconut palms grown on the plant forms. Fish and prawns in the channels between coconut plantations. Fodder crops like Guatemala grass, napier grass and guinea grass can be grown.
- Coconut and fish culture in salt affected lands: Coconut grows successfully even in the salt affected paddy fields. Fish + coconut in dry period. During rainy period salinity tolerant rice varieties could be cultivated in the same field with coconut and fish culture.
- Fruits, fodder and milch cattle: Space available between the fruit trees can be utilized for growing fodder crops like cowpea, rice bean, greengram and blackgram and fodder crops for cattle.
- Duck rearing: It contributes 7% of the poultry production. It is well suitable for coastal areas like West Bengal, Orissa, Tamil Nadu and Kerala. It is hardy and resistant to diseases and natural foraging. The breeds such as sylhetmet and Naggeswari are the native breeds of Eastern region. Kakhi Camphell is the recommended breed with a productivity of 300 eggs / bird / year. White perkin is exclusively for meat purpose and gains 3 kg body weight in 40 days.

Modules for hill and mountain agriculture

The development of land use systems at hill eco system should be based on watershed approach for resource conservation point of view. Among the factors responsible for determining the land use systems, people participation is a persuasive factor and agro climatic conditions are only to decide the nature of agricultural crops, trees or grasses. Watershed based farming system, appropriate soil conservation measures, mixed land use of agri-horti-sylvipastoral system, subsidiary source of income through livestock rearing, creation of water harvesting and silt retention structures at lower reaches are the important distinguishable sloppy agricultural land technologies on the hill farming situation.

The following are the major crop components in integrated farming system of hill and mountain agriculture.

i. Agri-silvipastoral system: Integrating agricultural crops along with pasture component termed as agri-silvipastoral system and also with tree component, which could be used as a fodder component. This system could support erosion control, improves organic, physical and chemical properties of the soil, recycling the nutrients, augment soil water availability and reclamation of acidic and degraded land

ii. Intercropping system: Shrubs and trees can be grown anywhere among the plantation crops, as shader or climber with number of shrubs or and trees varied from 100-300 nos. and fodder yield varied from 0.82 – 1.36 ton dry weight per ha peryear with carrying capacity of 1.2 – 2.1 sheep or goat per year.

iii. Live fence system: Shrubs and trees are grown as live fence along the boundary of the small land holding farmer. The plant spacing is 10-20 cm of the shrubs and 5 – 10 m for the trees. There will be 200 – 400 shrubs and 40 – 80 trees per ha with average fodder yield of 9.45 t dry weight per year and that could carry 14.4 sheep or goat.

iv. Three strata forage system: It is a technique of planting and harvesting of grasses and ground legumes (I stratum), shrubs legumes (II stratum) and fodder trees (III stratum) surrounding the food crop in such a way so that livestock feed is available year around.

v. Horti-agriculture system

- High altitude fruit crops: Apple, pear, pecan, plum, apricot, walnut, cherry
- Low altitude fruit crops: Pomegranate, mango, litchi, papaya, citrus, peaches, plums, kiwi, strawberry and olive cultivation are also gaining momentum in hilly zones.
- Vegetables during summer: Onion, green gram, tinda, Vegetables during winter: Cauliflower, cabbage, tomatoes, radish, carrot
- Orchard grass to supply feed for the animal *e.g.*, *Dactylis glomerata*, *Trifolium pratense*

vi. Animals: Cattle constitute 48 per cent of total animal population in the region. About 95% of those are local which is tiny and low milk yielding, varies from 1 to 1.5 litperday. The people keep a large herd not only for milk but for manure as well.

vii. Poultry: The poultry farming in hill areas primarily started as source of gainful employment in rural areas where small and marginal farmers, unemployed youths, ex-service men etc. opted for its supplementary source of income and for better family nutrition by raising small flocks of layers and or broilers rather than commercial specialized enterprises. Poultry showed relatively slower growth in hill areas than the fast national trends. Poultry farming is more popular in low and mid hill subtropical / sub-temperate regions as compared to high-hills temperate region. The constraints in this system are non-availability of quality stock, high cost of feed and lack of technical know how.

viii. Rabbit rearing: Himachal Pradesh is presently the largest Angora wool producing state in the country. It is estimated that out of 30 MT per annum Angora wool production, 20 MT is from Himachal Pradesh from 250 units. Angoral wool is popular for its superb whiteness, warmth, softer feel and fineness.

ix. Floriculture: Cut flowers which have great demand in International market is an apt choice in hilly areas. Gladiolus, marigold, carnation, lilium, tulip, chrysanthemum can be included.

x. Beekeeping: It improves the pollination and increases the yield of hilly crops like carrot (9-135 %) and apple (250-1500 %). 100 migratory colonies produces 15-35 kg honey per colony.

It is clear from the above results that farming system for different situations enhances the productivity, profitability, nutrition security of the farmer and sustains the productivity of the soil through recycling of organic source of nutrients from the enterprises involved. The best advantage of utilizing low cost /no cost material at farm level for recycling will certainly reduce the production cost and ultimately improve the farm income.

BIBLIOGRAPHY

AICRP – IFS Annual report – TNAU – (2016).

Jayanthi, C., Vennila, C., Nalini K. Chandrasekaran, B. (2009). Sustainable integrated management of crop with allied enterprises: Ensuring livelihood security of small and marginal farmers. Asia Pacific Tech Monitor. Jan – Feb issue. pp. 21-27.

Jayanthi, C., Mynavathi, V.S. and Ravisankar, D. (2013). Assessment of carrying capacity of crop livestock silivipastoral farming system. *Madras Agricultural Journal* **100(10-12):** 806-811.

Kalyan Singh, Bohra, J.S., Singh, Y. and Singh, J.P. (2006). Development of farming system models for the northeastern plain zone of U.P. *Indian Farming* **56 (2):** 5-11.

Thakur, (2004). Farming system: Issues and opportunities in North Western hills. Lead paper presented in the second national symposium on Alternative farming systems: Enhanced income and employment generation options for small and marginal farmers. Organized by FSRDA, PDCSR, Modipuram, Meerut. September 16-18, 2004.

Non-woven Jute Agro-Textiles for Improvement of Soil Quality and Horticultural Production: Example from Coastal Ecosystem

B. SAHA*

Quality Evaluation and Improvement Division, ICAR-NINFET
12, Regent Park, Kolkata-40, West Bengal, India

Corresponding author: E-mail: biplabsa@yahoo.com

Agriculture is the backbone of the Indian economy. Agriculture in India accounts for over 16% of the country's GDP and employs about 50% of the country's entire workforce. After the United States, India has the largest amount of arable land – land that is suitable for cultivation of crops. While India has claimed its place in the world as the largest producer of many fruits and vegetables, the country lags behind a big way in terms of yield and earnings. Indian farmer on an average receives anywhere between 10-23% of the price that the end consumer pays while in countries like the United States, farmers receive anywhere between 64-81% of the price (GOI, Report). Yield gaps of various fruits and vegetables like mangoes, bananas, potatoes, tomatoes, onions and fresh vegetables are staggering. It is undeniable that the country is nowhere in the vicinity of the sort of potential that can be achieved. Agro-textile utilization may help the agriculture community in attaining potential yield and enhance quality in agriculture/horticulture produce. Amongst its various benefits, agro-textiles assist in better soil management and protect produce from harmful external elements. Agro-textiles prevent the soil from drying out thereby increasing the crop yield, and improving product quality. Such textiles protect the farmer from harmful pesticides. Agro textile products like shade netting and thermal screens enable a saving of 40% on energy used for heating greenhouses. Farmers have also found that use of agro textiles brings about improvement in the quality of fruit and vegetables, uniformity of color and prevent staining (Agarwal, 2013). These benefits will provide farmers with enhanced productivity and increased yields resulting in further livelihood improvement of the stakeholders. Thus agro-textile can be the backbone of Indian agriculture.

What are agro-textiles?

Agro-textile is one of the smaller categories of technical textiles, with consumption accounting for around 8.2% by volume and 6.4% by value of the global technical textiles market in 2010. However, this sector is among those with the strongest growth predictions based on the projected increase in global population and the demand for higher quality food. The Food and Agricultural Organization predicts that global food production will have to increase by 70% from its current level to feed a population of 9.1bn by 2050. In developing countries, such as India, China and Brazil, the market is estimated to be growing by 8-10% a year. By value, Asia already accounts for around 60% of the total agro-textiles market by volume and 55% by value.

Non-woven agro-textile is defined by ISI Standard 9092 and CEN EN 29092 as a sheet of fibres, continuous filaments, or chopped yarns of any nature or origin, that has been formed by any means, and bonded together by any means, with the exception of weaving or knitting (Reliance Industries Ltd.). Non-woven Jute Agro-textiles (NJAT) are special textiles, which are manufactured by processing the jute fibres through garnetting cum cross lapping machine followed by needle punching loom for mechanical bondage. These textile structures are used as controlling environment for plants or animals in applications like agriculture, horticulture and animal husbandry.

Jute Agro-textiles (JATs) are designed and manufactured in such a manner that it could possess all the desired physical, mechanical and hydraulic properties required for effective application in Agri-horticulture & Forestry (Choudhury, 2010). These textile structures are used as controlling environment for plants or animals in applications like agriculture, horticulture and animal husbandry (Agarwal, 2013).

Non-woven Jute Agro-textiles (NJAT) used for agriculture varies from 250-750 gsm with thickness 3-6cm, width 100 ±10cm. They have very high porosity and absorb 500% water by weight and can retain moisture for long time. It has very high carbon to nitrogen (C:N) ratio. Apparent pore opening size varied from 230 in 500gsm to 247 micron in 300gsm agro-textiles. Thickness varies from 2.02-3.98mm. Fabric density varies from 0.10 to 0.14g/cc. Air permeability fluctuates between 20-22 cc cm^{-2} s^{-1} at 2mm water head pressure. Sectional air permeability varies from 8.50 cc cm^{-2} s^{-1} to 11.64 cc cm^{-2} s^{-1}. Cross directional breaking load varies from 41 to 141N in 300 gsm to 500 gsm agro-textiles whereas machine directional breaking load varies from 11 to 41 N. Tensile strength varies from 10-12kN/m in 300gsm to 500gsm agro-textiles. Cross-directional breaking strain varies from 22% to 28% and machine directional varies from 36-40% (Saha *et al.*, 2014).

The essential properties required for agro-textiles are tensile strength, resistance to solar radiation, resistance to ultraviolet radiation, abrasion resistance, stiffness and bio-degradation. The most important requirements of textiles for agricultural applications are weather resistance and resistance to microorganisms. Natural fibres like wool, jute, cotton are used where the bio-degradability of the product is essential. Natural polymer gives the advantage of biodegrading but has low service life compared to the synthetics (Agarwal, 2013).

The high carbon content of the agro-textile mulch stimulates the growth of soil microbes and increases their activity in the rhizosphere, which compete more successfully than plants for the limited supply of nutrients resulting in nitrogen immobilization. Although the nitrogen-depleting effect of mulch diminishes over time as it decomposes this nitrogen immobilization by microbes will probably have a greater impact on herbaceous plants and newly transplanted woody plants than on well-established trees and shrubs with extensive root systems.

NJAT contains 59.9% cellulose, 23.45% hemicellulose, 12.56% lignin, 1.1% fat and wax, 1.80% nitrogenous matter and 0.7% ash content. The high carbon content of the NJAT stimulates the growth of soil microbes and increases their activity in the rhizosphere when used as mulching material, which competed more successfully than plants for the limited supply of nutrients resulting in nitrogen immobilization. Although the nitrogen-depleting effect of mulch diminishes over time as it decomposes. This nitrogen immobilization by microbes will probably have a greater impact on herbaceous plants and newly transplanted woody plants than on well-established trees and shrubs with extensive root systems.

Jute Agro-textiles for resource conservation towards increasing horticultural productivity

Fruits and vegetable crops need a certain degree of environmental consistency to grow. However, in a country like India, weather patterns are very much unpredictable. Many fruits and vegetables grown across the country are sensitive to environmental parameters and often fall prey to unexpected fluctuations.

This is where agro-textiles stand to play an important role. Jute Non-woven Agro-textile (NJAT) provides the natural answer to ensure faster crop-and-plant growth. JAT helps retain soil humidity at conducive levels, arrests desiccation of soil and attenuates extremes of temperature due to the inherent characteristics of jute. It absorbs water / moisture upto about 5 times of its dry weight. On biodegradation, jute coalesces with soil, increasing its permeability and supplementing its nutrient level. NJAT fosters growth of vegetation even in arid and semi-arid zones much faster than under control conditions without use of manures. On top of it, NJAT can suppress weed-growth effectively without use of chemical herbicides. It provides all these advantages without affecting eco-ambience adversely at affordable and competitive cost (Choudhury, 2010). The selection of Jute Agro-textile depends on crop needs and geographical location. For any application of technical textiles in agriculture quality control tests are essential to ensure their effective performance.

Non-woven Jute agro-textile mulch (NJATM) mats have been tested by researchers on variety of crops at different locations of India to enhance yield and improvement of soil health. Bio-degradable mulch mats were tested to increase water conservation in the soil profile, conservation of degraded land, water retention capacity of soil, to enhance microbial activity at the root zone, suppress weed growth in horticulture applications and to enhance yield of the vegetable and fruit crops. They cover the soil, block light, prevent the competitive weed growth around main crop without affecting the growth of the plants and reduce evaporation from bare soil increasing water retention capacity of the soil. NJAT of 250, 300, 350, 400 and 500 gsm have been compared with control under different vegetable production systems. Efficacy of jute agro-textiles have been established in the following areas:

1. Soil conservation
2. Water retention and transmission
3. Soil Compactness
4. Weed suppression
5. Nutrient Enrichment
6. Enhancement of microbial population in the root rhizosphere
7. Enhancement of plant growth parameters

Soil conservation

Stabilization of slopes affected by landslides/slips

Jute geo-textiles were applied in the landslide prone areas on Mussoorie-Chakrata Road in the mid Uttaranchal Himalaya. The area of steep slopes drains into river Aglar below, a tributary of river Yamuna. Cultivable land of the area was converted to barren land due to landslide and washing of soil, which was abandoned and natural vegetation existed only in patches. It was observed that rehabilitation of degraded slopes with application of jute woven geo-textiles was more cost-effective than Jute non-woven geo-textiles and voluminous jute non-woven material incurred slightly higher cost of transportation. It was established fact that performance-wise woven textiles was better than non-woven and hence, for soil stabilization on the degraded slopes, so jute woven geo-textiles were preferred for that purpose. The soil nutrient status was found to improve in case of woven geo-textiles in terms of availability of NPK and organic carbon for growth of vegetation. Interestingly additional 0.55 ha area was brought under cultivation by farmers below the jute woven covered site. This area under full of debris was brought under cultivation once the upper catchment was treated (Nag, 2004).

The ultimate tensile strength jute woven and jute non-woven were respectively 194 and 1.45 Newton. The moisture content of the samples recorded at 0-15 cm and 15-30 cm depth respectively showed that the average moisture percentage under jute woven, jute non-woven and control were 16.6 (76%), 13.4 (42%) and 9.4 % respectively, where figures in parenthesis show percentage increase over control. Consequently overall vegetative growth was enhanced after soil stabilisation through jute geo-textiles (Nag, 2004). Non-woven Jute Geo-textiles (NJGT) and woven Jute Geo-Textiles (JGT) were used to check river bank erosion in Guptipara village of Hooghly district of West Bengal (Nag, 2004) (Fig. 1 and Fig. 2).

Fig. 1. Laying of jute geo-textile mulches on the river bank

Fig. 2. Levelling of land surface before laying jute geo-textile

After laying the fabrics rolls across the trench and along the slope from top down to the lowest water level suitable grass seeds were spread on the treated bank. A few saplings of suitable plants were also planted randomly on the bank for its better stabilization.

It was evident from visual observations that the non-woven fabrics showed higher growth rate of seedlings *i.e.* both coverage and growth as compared to woven fabrics. The growth of grass and increase in water level in the river were observed after 2 months from the date of installation of JGT with sporadic rain for a few days and heavy shower on only one day. However, light siltation was observed after a month. Moreover, the growth of grass under JGT was not uniform. Growth of grass in plots covered with non-woven was observed to be uniform (Length of grass approximately about an inch) whereas it was very insignificant in the plots covered with woven geo-textile appearing like a light green shade. The adjacent portions of field not laid with geo-textile wore a contrast appearance with full of cracks of wider hole, which subsequently may culminate into wide gullies. Inspection after about 3 months of laying revealed no sign of crack of surface nor erosion of top soil. Non-woven geo-textile covered field showed its supremacy over the woven one. The probable reason for retarded growth of grass in the woven portions was less porosity/voids in the fabric which decelerated the growth of grass. Sufficient moisture beneath the fabric was not available for proper growth and the dense fabric acted as an impediment for the plant to come out through it. The bank was more or less fully stabilised after an approximate period of 6 months.

Checking soil erosion from Agricultural Field

In loamy sand soil jute agro-textile was able to reduce soil loss by 96.1-96.3% and nutrient loss by 95.5-97.0% whereas, in case of sandy loam soil reduction of soil loss and nutrient loss was found to be 49% and 72% respectively (Choudhury, 2010). Jute Agro-textile mulches of 500gsm was able to reduce soil loss from 34 t ha^{-1} to 29 t ha^{-1} in upland rice. Soil loss due to erosion reduced from 83t/ha to 67t/ha by application of 500gsm agro-textiles. Jute agro-textiles were found to be more effective when used in combination with green crop in reducing soil erosion and controlling nutrient loss (Choudhury, 2010).

Water retention and transmission

Studying water availability, residual water content (RWC%) and chlorophyll content index in case of pointed gourd under different mulches, it was observed that percentage moisture varied from 17.5% to 28.4%. Highest moisture percentage was observed in case of 300 gsm mulched plots followed by 250 gsm and 200gsm agro-textile plots. However no significant difference in moisture content (%) was observed between 250 and 300 gsm plots. Residual Water Content (RWC%) showed similar trend, which varied from 81.3% to 93.2 % (Saha and Nag, 2013).

In tomato cultivation at alluvial soil the following trend of soil moisture contents reported under different types of NJATM: 800 gsm > 600 gsm > 400 gsm > 200 gsm > control at 15 cm soil depth. The data further showed that the average moisture use efficiencies of the crop increased by 26.50 per cent due to the treatments of NJATM over control, the highest 40.69 percent of which occurred under 600 gsm NJATM (Adhikari *et al.*, 2018).

Results clearly revealed much variation of all the indices of soil structure and their stability due to application of various treatments. The values of mean weight diameter (MWD), geometric mean diameter (GMD), structural coefficient(SC) and water stable aggregates (WSA) were found highest in 600 gsm NJATM followed by 800gsm, 400 gsm and 200 gsm. These indicated that 600gsm NJATM could be effective ameliorative towards improving stability of soil structure (Adhikari *et al.*, 2018).

As mulch changes the surface properties and pore size distribution of soil through differential root growth, water transmission properties through soil surface and profiles also vary. Cumulative infiltration rate varied from 2.8cm in controlled plots to 8cm in 300gsm NJATM plots in pointed gourd cultivation system in alluvial soil. It was observed that during initial stages infiltration rates were very high across the treatments in capsicum production system. Initially it varied from 1.25cm hr^{-1} in control plots to 3.0 cm hr^{-1} in 300 gsm plots. In case of stabilisation after 2hrs of infiltration rates were found to vary between 0.4 to 1.0 cm hr^{-1}. Cumulative infiltration in capsicum varied between 2-3.6 cm (Saha and Nag, 2013).

Available water capacity, in capsicum production system at alluvial soil varied from 30% to 48%, and was found to be higher after every irrigation in case of NJATM treated plots over control. It did not vary much within different treatments of NJATM (Saha *et al.*, 2016). Available water capacity varied from 14% in control to 24% in case of 500 gsm NJATM in capsicum production system of coastal alluvial soil. Yield increase of 170% to 180% was observed in case of 300 and 400 gsm NJATM mulches over control.

The soil moisture percentage observed in both capsicum and pointed gourd production system showed significant variation between NJATM and other mulching materials in new alluvial soil and coastal alluvial soil after irrigation cycles specially third and fourth irrigation. In both cases, 300gsm NJATM plot exhibited best performance in respect of soil temperature and moisture conservation in old alluvial soil (Saha *et al*., 2006) whereas, 500gsm NJATM performed better in coastal alluvial soil.

Available water capacity in broccoli varied from 20% in control to 40% in 400gsm NJATM at coastal alluvial soil. It was observed that vegetation was more vigorous in mulched plots than control. As the total porosity was least in 500gsm plots, evaporation from soil was very less and moisture retention increased. Difference between intial and final moisture increased in later cycles because of rapid decrease in initial moisture due to increase in temperature. Consequently, Irrigation water requirement was reduced by 25-50% in case of NJATM over control plot in broccoli production system. Irrigation water requirement was 25% less in 300gsm plots and 50% less in 500gsm plots over control in Broccoli. It was17% less in 300gsm plots and 45% less in 500 gsm plots over control in capsicum production system in coastal alluvial soil (Subba, 2015).

However, available water capacity increased from 11% in control to 16% in case of 400 gsm NJATM, followed by 15% and 13% in case of 350gsm and 300gsm at red and laterite soil (Saha *et al*., 2016).

Soil moisture content in 15, 30, 60 and 90 DAP (days after planting) was highest in 400 gsm NJATM followed by moisture content in 350 gsm NJATM > 300 gsm NJATM) > black polythene > rice straw) > no mulch treatment respectively in decreasing order in broccoli production system at red and laterite soil. Mulched treated plot showed higher soil moisture content compared to control because of their increased water retention, reduced evaporation and reduced weed population density (Manna et al., 2018). High surface soil moisture and reduced evaporation under mulches have been reported under several studies (Ramakrishna *et al*., 2006; Jordan *et al.*, 2010).

Available water capacity was found to be highest in case of 400gsm NJATM mulches and varied from 35.7% to 45.0% compared to the bare control plot in bhindi at coastal alluvial soil (Subba, 2015).

Maize is grown as preferred *kharif* crop of red and laterite soil. In maize cultivation system available moisture varied from 10% in control to 22% in 400 gsm NJATM mulched plots.

In bitter gourd cultivation system at inceptisol, soil moisture at available water capacity varied from 25 to 36%. Water holding capacity was found to vary from 40% in control plots to 49% in case of 350 gsm in NJATM plots.

Water holding capacity under NJATM mulched fields was found to increase by 22.5% over control in french bean production system at red and laterite soil.

Effect of agro-textile mulches on seepage control in open channel was studied at B.C.K.V, Mohanpur, West Bengal, India (Chatterjee and Roy Choudhury, 2005). Comparing four agro-textiles 250 gsm with single side polythene coat, 300gsm with single side polythene coat, 250 gsm with both side polythene coat, 300gsm with both side polythene coat, they showed that seepage loss reduced from 5.2 litre m^{-2} day^{-1} in case of 250 gsm with single side polythene coat to 2.2 litre m^{-2} day^{-1} in 300gsm with both side polythene coat.

Effect on Soil compactness

Jute agro -textiles as surface cover materials have various potentials for maintaining soil quality and protecting the soil against any form of degradation. Sharp improvements of bulk density, porosity, moisture use efficiency as well as better aggregation and well stabilization of soil aggregates occurred due to application of each strength of jute agro textiles (Adhikari *et al*., 2018).

Bulk density of soil decreased by 0.03 (2.3%), 0.05 (3.8%), 0.02(1.5%) and 0.02 (1.5%) with simultaneous increase in porosity by1.61 (3.2%), 2.3 (4.6%), 0.7 1(1.42) and 0.41(0.8%) in NJATM 800 gsm, 600 gsm, 400gsm and 200 gsm respectively. The results revealed that the porosity increase aeration and root growth towards uninterrupted availability of nutrients (Adhikari *et al.*, 2018).

Weed suppression

Studies on effect of NJATAM on weed population density revealed that density of broad-leaved weed, sedges and grasses could be reduced substantially through application of NJATM treatments.

Weed emergence in tomato cultivation system was reduced by 62% with jute agro-textiles only. However in combination with post-emergent translocated weedicide rate of reduction increased to 78%. In dry period soil moisture % increased by 40.5% over control which increased up to 54.9% in combination with post emergent contact weedicide. Yield of tea was found to be highest (1650 kg ha^{-1}) in case of plots where agro-textiles were applied in combination with pre- emergent translocated weedicide in comparison to control (1300 kg ha^{-1}) (Choudhury, 2010). In case of groundnut, weed density was from 3.5 kg m^{-2} to 3.1 kg m^{-2} by application of JAT. Weed density in sesame reduced from 0.47 kg m^{-2} to 0.27 kg m^{-2}, in black gram it reduced from 0.86 to 0.52 kg/m^2 and in upland rice it reduced from 0.88 to 0.72 kg m^{-2} (Choudhury, 2010). NJATM could reduce weed growth by 65%. Addition of weedicides could enhance the extent of suppression by a further 13% maximum (Choudhury, 2010).

Weed population data under various treatments reveal that *Chenopodium album* and *Oxalis corniculata* are mostly prevalent in the area. More than 80% of the weed suppression was observed under 500gsm NJATM whereas suppression varies between 56-59% over control in case of 300 and 400 gsm NJATM (Subba, 2015). Weed suppression capacity was found to be highest (75%) in case of 350 and 400gsm NJATM followed by 70% in case of 300 gsm plots in red and laterite soils (Manna *et al.*, 2018).

Application of NJATM of 500gsm between rows in pineapple cultivation plots at Tripura reduced the weed density by 43% (Datta *et al.*, 2005).

Weed suppression varied from 45% in case of 300gsm plots to 77% in 500gsm plots over control in Bhindi grown in coastal alluvial soil. Weed suppression of 63% was observed in 400gsm agro-textile plots (Subba, 2015).

Weed population density of various treatments revealed that density of broad leaved weeds, sedges and grasses was highest in 30 days after planting (DAP) compared to mulched plots in broccoli cultivation system at red and laterite soil. Subsequent increase in weed density at 60 DAP was recorded for all the mulched plots, and at 60 DAP, highest density of such three types of weeds was again noticed in no mulch compared to others. Lowest density of broadleaved weed, sedges and grasses (0.50 number per square meter area) at 30 DAP were recorded in 400 gsm NJATM, 350 gsm NJATM and 300 gsm NJATM treatments respectively.

Study revealed that weed population was significantly less in mulched plot compared to non- mulched one as the mulches reduced light, which stressed existing weeds and prevented the germination of many weed species, especially those with small seeds. The physical barrier created by mulches prevented weeds from emerging, though this effect was temporary and disappeared as mulches decomposed.

Nutrient enrichment

Studying the jute sleeves made from agro-textiles, it was observed that degraded sleeves added nutrient to the soil when saplings were transplanted along with the sleeves without causing any environmental hazard. Healthy growth of saplings was observed with survival rate of 90% (Chowdhury, 2010). Organic carbon% increased from 0.42 to 0.79%, available nitrogen increased from 44 to 85 kg ha^{-1}, available P increased from 11 to 35 kg ha^{-1} and available K increased from 147 to 265 kg ha^{-1} in NJATM plots of bitter gourd production under new alluvial soil (Saha, 2016). Significant increase in availability of nitrogen, phosphorous and potassium on NJATM treatment over control was observed in tomato production system in new alluvial soil. The study reveals that the increment of organic carbon by 0.22(48.89%), 0.24(53.33%), 0.17(37.78%) and 0.16(35.56%) respectively in 800 gsm, 600 gsm, 400 gsm and 200gsm NJATM (Adhikari *et al.*, 2018).

Soil organic carbon content increased compared to that of control treatment, and its content was highest (0.65%) in plot treated with 350 gsm NJATM in red and laterite soil. Although weed population density reduced in mulched treated plot compared to control, the soil organic carbon content increased with mulching treatments because of higher broccoli yield and its contribution to organic C in hidden half through the roots and crop residues. Besides, application of NJATM having higher C/N ratio and lignin content (12.56%) favoured nutrient immobilization and organic matter accumulation probably as a result of organic material added with exhausted mulch (Manna *et al.*, 2018).

Studying nutrient enrichment characteristics in coastal alluvial soil, it was observed that organic carbon (%) increased from 0.11% in control to 0.32% in 400gsm NJATM. Mild increase in available Phosphorus was observed from 1.0 kg ha-1 in control to 2.7 kg ha^{-1} in 300gsm and 400gsm NJATM plots. Available potassium in kg ha^{-1} was also increased from 16.5 kg ha^{-1} in control to 98 kg ha^{-1} in 300gsm agro-textile plots (Saha, 2016).

Available N content in post-harvest red and laterite soil again increased compared to control plot and its value was highest (135.75 kg ha^{-1}) in 350 gsm NJATM treatment. The increase in available nitrogen under mulch treated soils compared to control was probably due to optimum moisture availability, increased mineralization of soil organic N, residual nitrate accumulation in the soil profile and reduction in N loss from the soil profile (Manna *et al.*, 2018).

Again, available P and K contents in post-harvest mulched red and laterite soil increased compared to control. The highest available P content (22.50 kg ha^{-1}) was recorded in plot treated with both 350 and 400 gsm NJATM. Again, highest (119.75 kg ha^{-1}) available K content was recorded in 350 gsm NJATM treatment which was, however, statistically at par with plot treated with 400 gsm NJATM. The higher available P and K content of soils under mulching may be attributed to better hydrothermal regimes, more proliferation of root system, higher root biomass and efficient weed control which released potassium in soil and minimized the P mining. Besides, production of organic acids during the decomposition of mulching materials including NJATM complex the metal cations Ca, Al and Fe, thereby helping in solubilization of native P and reduction in P sorption (Manna *et al.*, 2018).

Overall, available nutrient contents of soils of NJATM treated plots were higher compared to no mulch and other mulching material because of decomposition of NJATM under appropriate water and temperature levels and release of available nutrients in the soil for root uptake or microbial use as supported by Chalker-Scott (2007).

Enhancement of microbial population in root rhizosphere

NJATM influenced the microbial growth and population in rhizosphere of different horticultural crop production systems.

Population of total soil bacteria increased from 1.67×10^7 to 2.57×10^7 in 500gsm NJATM. However, population of nitrogen fixing bacteria increased from 7.25×10^5 to 32.5×10^5 in 500gsm NJATM in red and laterite soil (Saha, 2016). Bacterial population decreased drastically after the month of January in control due to exposure of soil to high temperature. It was observed that in case of all the treatments, bacterial population increased exponentially after the middle of January due to favourable temperature, humidity and anaerobic condition under NJATM (Subba, 2015).

Data on fungal population reveals that fungal population under NJATM decreased up to middle of January and increased gradually up to harvesting period. However the population remained same in case of control from middle to end of crop growth stages (Subba, 2015).

Comparing microbial population at root zone in bhindi grown in coastal alluvial soil, it was observed that nitrogen fixing bacteria rhizobium varied from 8.8×10^7 CFU to 24×10^7 CFU. Highest population observed in case of 400 gsm NJATM followed by 350gsm plots. Fungal population increased upto harvesting stage under all the treatments.

However, the population in 500gsm plots are lower than 400gsm plots due to more anaerobic condition, which is detrimental to fungal growth.

Population of nitrogen fixing bacteria increased steadily in case of NJATM plots from 64×10^5 CFU in control to 165×10^5 CFU in 400 gsm NJATM plots in french bean production system in red and laterite soil. Increase in CFU is significant in both 1% and 5% level of significance in french bean cultivated plots. Microbial population was less in red and laterite soil due to poor nutrient status and water retention capacity.

Studies on effect of mulches on rhizosphere soil microbial population in broccoli production system in red and laterite soil revealed highly significant variation. Results revealed that the initial bacterial population in soil was lowest (35.5×10^6 cfu g^{-1}) and highest (46×10^6 cfu g^{-1}) in no mulch and black polythene mulch respectively. It was observed that bacterial population in soil increased significantly from 30 Days after planting (DAP) to 60 Days after planting (DAP) due to favourable temperature, humidity and anaerobic condition under NJATM (Subba, 2015) and at 60 DAP, highest bacterial count was observed in 350 gsm NJATM. There was severe reduction in bacterial population in soil from planting to harvesting in almost all the treatments due to prevalence of high soil temperature. However, that of the population of actinomycetes and fungi in soil increased from planting to harvesting (Manna *et al.*, 2018). The inhibitory effect of root exudates of grasses on bacteria was reported by Gopalkrishnan *et al*. (2009).

The initial population of fungi was ranged from 41.75×10^3 to 44.50×10^3 cfu g^{-1} in rice straw and no mulch treatment respectively. At 60 DAP, it was observed that fungal population under almost all the treatments decreased from its initial value and thereafter increased gradually at harvesting period. At 60 DAP, highest fungal population (42.75×10^3 cfu g^{-1}) was recorded in 350 gsm NJATM. At harvest also, the highest fungal population (54.0×10^3 cfu g^{-1}) was recorded in 350 gsm NJATM. The initial population of actinomycetes ranged from 69.75×10^4 to 84.50×10^4 cfu g^{-1} in 300 gsm NJATM and 350 gsm NJATM treatment respectively. At 60 DAP, it was observed that population of actinomycetes under almost all the treatments decreased from its initial value and thereafter increased gradually at harvesting period. At 60 DAP, highest population of actinomycetes (66.25×10^3 cfu g^{-1}) was recorded in 400 gsm NJATM which was, however, statistically at par with 350 gsm treatment. However, at harvest, the highest population of actinomycetes (134.75×10^3 cfu g^{-1}) was recorded in 400 gsm NJATM. Thus, NJATM greatly influenced actinomycetes population in rhizosphere soil of broccoli where population appeared to be increased from planting to harvest. It may be due to higher amount of availability of carbon during leaf fall towards maturity (Manna *et al.*, 2018).

Enhancement of plant growth parameters

Studying the effectiveness of NJATM in plant growth in semi-arid region in West Bengal, it was found that growth of plants were more pronounced and almost double over control conditions (Choudhury, 2010).

Studying the effect of NJATM as seed bed cover in plant growth parameters, it was observed that number of seedlings per m^2 increased from 599 to 793, height of plants increased from 7.4 to 9.9 cm and survival rate of the seedlings increased from 80-95%. Root strike percentage was found to be 83% in nurseries of tea plants in Assam (Choudhury, 2010).

In the afforestation at loamy sand soil of semi-arid zone, it was observed that, plant height was 140cm after 3months and 180cm after 6 months with NJATM in comparison to 80cm after 3months and 100cm after 6 months in control. Thus height of the plants increased by 80% and healthy growth of plants were observed (Choudhury, 2010).

In case of groundnut, increased pod yield form 110 t ha^{-1} to 125 t ha^{-1} and haulm yield from 1.52 t ha^{-1} to 1.85 t ha^{-1}. In case of black gram pod yield increased from 0.25 to 0.62 t ha^{-1} and haulm yield increased from 0.44 to 0.87 t ha^{-1}. For upland rice grain yield increased from 1.03 to 1.45 t ha^{-1} whereas straw yield reduced from 2.13to 1.84 t ha^{-1} (Chowdhury, 2010).

Chlorophyll content index (CCI), one of the important indicators of crop growth varied from 20.8 in case of control to 47.8 in 300gsm NJATM plots in capsicum production system(Saha and Nag, 2013).

In chili production system at inceptisol of Nadia district in West Bengal, it was observed that all the growth parameters like plant height, number of branches and yield of crop showed best performance in case of 400gsm NJATM compared to other agro-textile mulches and control (Saha *et al.*, 2016) (Fig. 3).

In cauliflower curd weight increased from 450g in control to 715g in case of 300 gsm NJATM at coastal alluvial soils of South 24 Parganas district, West Bengal.

In broccoli average curd weight increased from 280g in control to 422g in case of 300gsm NJATM at the coastal alluvial soil of South 24 Parganas district, West Bengal. Curd weight of Broccoli was more than threefold higher over control in case of 500gsm mulched plots. Yield of Broccoli was found to be 7.0-8.5 t ha^{-1} in case of NJATM plots whereas it was 3.0 t ha^{-1} in case of control in case of red and laterite soils.

Comparing crop growth parameters, it was observed that no of leaves, height of plants, weight of leaves and yield of bhindi per plucking per plot was highest in case of 400gsm NJATM plots. Yield varied from 0.85 kg per $10m^2$ per plucking in control plots without mulching to 2.0 kg per $10m^2$ per plucking in case of 400gsm NJATM plots at alluvial soil (Subba, 2015).

Maize yield in red and laterite soil varied from 4q to 8.5 q ha^{-1} in rainy season under NJATM. Highest yield was observed in 300gsm mulched plots followed by 350 and 400gsm plots.

Fig. 3. Cultivation under Application of NJATM

180-190% increase in yield was observed in bitter gourd at new alluvial soil in case of 250 gsm NJATM over control at Nadia District of West Bengal. Weight of one capsicum fruit increased from 40g to 60g under NJATM over control in capsicum grown under coastal alluvial soil.

Highest yield of capsicum (8.2 t ha^{-1}) and pointed gourd (14 t ha^{-1}) were obtained in NJATM plot in alluvial soil, which were significantly higher over control (Saha *et al*., 2006).

NJATM of 300 gsm has increased yield of mosumbi about 3 times more than the yield obtained in controlled plots in arid horticulture and substantial increase in yield of turmeric about 1.3 times of untreated area could be obtained with 250 g m^{-2} NJATM (Nag *et al.*, 2005).

Application of 500gsm NJATM in one ha of mango orchard for five years enhanced the yield of fruit by 33% and increased selling price by 30% due to better quality and resulting additional return on investment (ROI) by 98% (Adhikari, *et al.*, 2018)

The yield of tomato were 39.80 t ha^{-1}, 42.69 t ha^{-1}, 37.08 t ha^{-1}, 30.84 t ha^{-1} and 24.77 t ha^{-1} in the plots of NJATM 800 GSM, 600 GSM, 400 GSM, 200 GSM and control (farmer's practice respectively. Significantly highest ($P<0.05$) fruit yield was recorded in plots of NJATM 600 GSM. Response of fruit yield of tomato over control due to each treatment were 15.03 t ha^{-1} (60.68%), 17.92 t ha^{-1} (72.34%), 12.31 t ha^{-1} (49.70%) and6.06 t ha^{-1} (24.47%) in respectively plots of NJATM 800 GSM, 600 GSM, 400 GSM, 200 GSM. The yield of tomato significantly increased ($P<0.05$) with the application of each of the different types of treatments over control (Adhikari *et al.*, 2018).

Highest yield of 8.53 t ha^{-1} in broccoli was observed in plot treated with 350 gsm NJATM. The superiority of bio-degradable 350 gsm NJATM over other thickness of NJATM and rice straw, polythene mulch or no mulch might be due to the beneficial effect of increased moisture conservation, increased organic carbon and nutrient status along with high weed control efficiency (Manna *et al.*, 2018).

Biodegradability of agro-textile mulches

Around 43% fall in strength in 300 gsm agro-textile mulches and 30% fall in strength in 400 gsm agro-textile mulches were observed after four months of exposure and usage as mulching materials respectively at red and lateritic soil. In the case of 250 gsm 56% loss in strength has been observed in cross direction and 8.5% loss in strength in machine direction of the fabric. Based on this information even after deterioration, the 400 gsm fabric strength is better than others for long duration horticultural crops and others fabrics are better in case of the existing short duration (75-100 days) horticultural crops (Saha *et al.*, 2016).

Conclusion

The experimental results narrated above lead to suggest that application of NJATM enhances improvement in soil health and yield of horticultural crops through better moisture and nutrient availability, favourable soil structure, increase in microbial population in rhizosphere, suppression of weed growth. In spite of that, Indian scenario of jute agro-textiles is in a very primitive stage where uptake of most products is extremely low. Various factors contribute to this- such as lack of awareness and hesitation in adopting globally proven cost effective technologies, absence of required standards to ensure product quality and implementation guidelines, absence of product specifications to define standard manufacturing properties, unorganized structure of cultivation compounds difficulty in penetrating the market, affordability for a majority of the broad target group for NJATM, deterrents for entrepreneurs in setting up capital intensive units for NJATM due to lack of skilled manpower (Govt.of India report). Keeping in view of the above issues we need to grow awareness among stakeholders regarding benefits of jute agro-textiles through aggressive front line demonstrations, making the products cost-effective, development of eco-label increasing its availability and development of entrepreneurship. Most emphasis should be given to application of jute agro-textiles in high value horticultural crops and recurring use of the same products for multiple seasons.

BIBLIOGRAPHY

Adhikari, N., Saha, A., Bandopadhyay, P., Mukharjee, S., Tarafdar, P. K. and De, S. K. (2018). Efficient use of jute agro textiles as soil conditioner toincrease tomato productivity. *Journal of Crop and Weed* **14(1):** 122-125

Agarwal, S. K. (2013). Applications of textiles in agriculture. *International Journal of Advance Research In Science and Engineering* **2(7):** 9-18.

Chatterjee, P. and Roychoudhury, M. (2005). in *"Lining of open channel with Geo-textile and performanve on seepage control" project report submitted in partial fulfilment of B.Tech in Agri. Eng. at B.C.K.V. ,Mohanpur Nadia*.

Choudhury, P. K. (2010). Jute agrotextiles its properties and applications. www.jute.org/Documents_Seminar.../JAT_IJIRA_KK_06-05-10.pdf

Datta, M., Singh, N. P, Choudhury, P. K, Mitra, S. (2005). In Jute Agro-textiles-its uses in agriculture. Published by N.P.Singh, ICAR Research Complex for NEH Region, Tripura Centre, Lembucherra-779 210 Tripura. www.tripuraicar.nic.in/publication/.../JUTE%20AGROTEXTILE.pdf

Gopalkrishnan, S., Watanabe, T., Pearse, S. J., Ito, O., Hossain, Z.A. K. M. and Subbarao, G. V. (2009). Biological nitrification inhibition by Brachiaria humidicola roots varies with soiltype and inhibitis nitrifying bacteria, but not other major soil microorganisms. *Soil Science and Plant Nutrition* **55(5):** 725–733.

Government of India Report (2013). Study on Developing Measures to Promote the Use of Agrotextiles in India. www.technotex.gov.in/**Agrotextiles**/Study%20on%20Developing%20Measures.

Manna,K., Kundu, M.C., Saha, B., Ghosh, G. (2018). Effect of nonwoven jute agrotextile mulch on soil health and productivity of broccoli (Brassica oleracea L.) in lateritic Soil. *Environment Monitoring and Assessment* **190(2):** 1-10. https://doi.org/10.1007/s10661-017-6452-y

Nag, D. (2004). Final report of AP Cess Fund sponsored project on *Development of geo-textiles and its blends for agro-horticulture production*.

Nag, D., Choudhury, T. K., Debnath, S., Ganguly, P. K. and Ghosh, S.K. (2005). Efficient Management of Soil Moisture with Jute Non-woven as Mulch for Cultivation of Sweetlime and Turmeric in Red Lateritic Zone. *Journal of Agricultural Engineering* **45(3):** 59-62.

Saha, B., Debnath, S., Roy, S.B. and Das, D. (2016). Performance analysis of crop specific agro-textiles. Annual Report, ICAR-NIRJAFT, 12, Regent Park, Kolkata-700040

Saha, B., Nag, D. (2013). Effect of geo-textile mulch on Rhizosphere, Root Growth, Soil Physical Properties and yield of horticulture crops.in *Book chapter of Diversification of Jute and Allied Fibres: Some recent Development edited by Satapathy K.K.and Ganguly P.K.* pp:115-120.

Saha, B., Prasad, L.K., Harris, Abul, A. , Sikka A.K. and Batta, R.A. (2006). Effect of geo-textile mulch on soil moisture, temperature and yield of vegetable crops grown in planes of Bihar. *International Journal of Tropical Agriculture* **24(1-2):** 153-157.

Subba, R. (2015). Study on microbial population in rhizosphere under different agro-textile mulches in vegetable production system. A dissertation work of a M.Sc student of Agricultural Bio-technology of Integrated Rural Development and Managemnt, Ramakrishna Mission Vivekananda University, Narendrapur pp.46.

Spawn Collection from Estuarine Systems for Coastal Aqua-farming: Sustainability Issues and Way Forward

DIBAKAR BHAKTA*, RANJAN KUMAR MANNA, SRIKANTA SAMANTA and BASANTA KUMAR DAS

ICAR-Central Inland Fisheries Research Institute, Barrackpore, Monirampore, Kolkata-700 120, West Bengal; India

**Corresponding author:* E-mail: dibakar.bhakta@icar.gov.in

India is gifted with a long coastline (8118 km) and vast stretches of coastal wetlands. Estuaries and backwaters, which also include mangroves, mudflats, bays, etc., are extended over a large part of the coast. The estuarine ecosystems are one of the most productive habitats of the world which gives suitable environments for the growth and survival of estuarine-marine animals (Barbosa *et al.*, 2012). Estuarine water bodies are recognized as one of the most modified and biologically threatened environments (Blaber, 1988). The east coast of India has a rich estuarine ecosystem formed by the Ganges and Brahmaputra river systems. Besides, numerous large and small estuaries exist both on the east and west coast of India formed by rivers joining the Bay of Bengal and the Arabian Sea, respectively.

Estuarine fisheries are characterized by economically and biologically important resources that provide food and income. The average yield of estuarine fish production in India was estimated to vary from 45 to 75 kg ha^{-1} (Jhingran and Ghosh, 1978; Sugunan, 2010). The inter-dependence of the adjoining marine and estuarine zones for the completion of the life cycle of finfish and shellfish species is indispensable (Chao, 1986). Estuarine fishes can be divided into two broad categories according to the place where they spawn: in estuarine systems or the sea. The life cycle of many marine species usually involves a juvenile period that is predominantly estuarine and a primarily marine adult stage (Wallace, 1975a). Although some species may attain sexual maturity within the estuarine environment, spawning mainly occurs in the sea (Wallace, 1975b), where a relatively stable marine environment is more suitable for the survival of the egg, embryonic and larval stages.

With the expansion of brackish water aquaculture in coastal areas, there is a considerable increasing demand for spawns of fin and shellfishes. As per the World Bank (2002), around 0.42 million individuals are involved in the collection of shrimp seeds from the estuaries and coastal areas in India.

Estuaries as the potential fish breeding grounds

Estuarine environments are recognized as a highly potential resource for fishery development as those areas act as a hotspot for feeding, spawning, and nursery grounds for most of the fin and shellfishes. Migration is a natural phenomenon for maximum fishes for spawning; few species migrations are intra-environmental, restricted to shorter routes of migrations, while other trans-environmental migrants travel hundred to thousand km. Estuarine environments act as intermediate habitats between the sea-freshwater and eco-biologically rich, act as a favored destination for both freshwater and marine fish and shellfish species. Migratory fishes visit estuaries in search of breeding and nourishment purposes and also for feeding and fattening reasons. Estuaries are considered the most important seed collection centers for coastal aquaculture activities, as most of the Penaeidae larvae harbors estuaries as their nursery grounds (Brinda *et al.*, 2010; Goswami and Goswami, 1993). There are certain reports on the immigration of prawns' post-larvae and fish juveniles into the estuarine and brackish waters of the Indian coast (Gopalakrishnan and Rao, 1968; Kuttyamma, 1975; Ramamurthy, 1982; Bhaumik and Mitra, 2013). Occurrences of mangroves, macro-vegetations, and algal beds are very important which act as a suitable environment for the distribution of the fin and shellfish seeds in the estuarine habitats. The preferences of aquatic weed dominated areas for the availability of *Penaeus semisulcatus* in the Pulicat Lake was reported by Gopinathan (1978), as well as Vellar estuary (Sambandam *et al.*, 1982) and Marakanam estuary (Victors and Venkatesan, 1982). Studies have been revealed that an appreciable amount of *Penaeus monodon* seeds have also been available in Kottakkudy, Uppar, and Kottakkarai estuaries (Bose *et al.*, 1980; Sambandam *et al.*, 1982).

Targeted species for seed collection

The targeted species for seed collection usually depends upon the local demands for brackish water aquaculture and varies from one state to the other. The targeted species from the Hooghly-Matlah estuarine systems for the *bheris* (estuarine fish farm) of coastal districts of West Bengal is *Mystus gulio*, *Terapon jarbua*, *Lates calcarifer*, *Chelon parsia*, *Mugil cephalus*, *Scatophagus argus*, *Sillago sihama*, *Rhinomugil corsula* among fin fishes; *Penaeus monodon*, *Macrobrachium rosenbergii* among prawns and *Scylla serrata*/*Scylla olivacea* among crabs (Fig. 1). Prawn seeds and the fries of milkfish (*Chanos chanos*) are found to be the targeted species from the Rushikulya estuary, located in the state of Odisha. The peak occurrences of milkfish seeds have been reported during August-September, and also during April, and collections from both seasons are used in the brackish water aquaculture systems.

According to De and Sinha (1997), the targeted commercially important seeds from the Hooghly-Matlah estuarine systems were reported as *Penaeus monodon* along with *Penaeus indicus*, *Metapenaeus brevicornis*, *M. monoceros* and the fin fishes *Chelon parsia*, *C. planiceps*, and *Lates calcarifer*. Post-larvae of Penaeus indicus is found to be the most potential candidate species in the brackishwater aquaculture in the state of Tamil Nadu and predominantly collect from the estuarine environments of Cauvery, Adayar, Kodayar, Thamiraparani, Palar, and Vaigai (Silambarasan *et al.*, 2013). Post-larvae of *Penaeus indicus* along with *P. monodon* were also found to the most targeted species in the estuaries of Kottakkarai, Uppar, Vaigai, and Kottakkudy in the Ramnad district of Tamil Nadu.

Fig. 1. Collection of *Penaeus monodon* post-larvae by a fisherwoman at Harwood Point in Hooghly estuary

Seeds of *Macrobrachium rosenbergii* were predominantly being collected from Tapti estuary but now stopped due to the non-availability of estuarine habitat. From the Narmada estuary, however, the collection is continuing for brackish water farming as well as to stock in the reservoirs. The Pearl spot, *Etroplus suratensis*, is mainly found in the south-west coast and east coast of India, extensively cultured in Kerala in both brackish water and freshwater environments. Being the low fecund fish, despite standardization of the breeding techniques, hatchery-produced seeds cannot meet the local demand and are forced to depend on natural seed collections.

Factors responsible for spawn's abundance

The tidal magnitude and its nature have a significant influence on the spawns' abundance. It has been reported that a major influx of quality of seed occurs within one hour of the high tide phase (Bhaumik and Mitra, 2013). According to them, at the Indian Sunderbans, during this period spawns of *Penaeus monodon*, *Metapenaeus brevicornis*, *M. monoceros*, *P. styliferus*, *Chelon parsia*, and *C. planiceps* are available with the highest amount, whereas in the latter part seeds of *P. indicus* are available. Gopalkrishnan *et al.* (1975) reported that at Hooghly-Matlah estuarine systems, high tide brought mostly the seeds of *P. monodon* and *Mugil parsia* and other prawn seeds during low tides at the Diamond harbor areas.

Bhaumik and Mitra (2013) performed detailed studies on the occurrence of seeds of fin and shellfishes in the Sundarbans estuarine systems during 1988-1994 and reported that lunar periodicity influences the availability of the seeds. The lunar phase controls the tidal amplitude and thereby regulates the availability of fin and shellfish seeds. In all the six estuaries studied (Hooghly, Matlah, Saptamukhi, Thakuran, Vidya, and Jheela), the maximum seed collections were achieved on 3^{rd} day of the lunar phase and compared to the new moon phase, collection was better during the full moon phase. According to their studies, during the seventh to the eleventh day of the lunar phase, very negligible seeds were available.

Methods of collections of spawns

Specific gears are employed for the collection of finfish seeds and shellfishes post-larvae from different coastal systems. Such gears are area-specific and time to time modified by the collectors as and when required, and a few of such devices are mentioned below:

Shooting nets

Shooting nets are found one of the most common devices to collect both fin and shellfish seeds. It is a funnel-shaped net with finely woven netting and operated in current-driven shallow margins of the estuarine systems. The length of such net varies from 10-22 ft and initially, both the ends remain open. At the cod-end of such net fine mesh clothes, locally also called *gamcha* are being attached which looks like monk's hood (Fig. 2). The spawns which are driven by the current move inside the shooting net, being trapped in the smoothen *gamcha* and then collected cautiously. Sometimes, while the shooting net is operated at a deeper portion of the water, a small boat is used to collect the spawns from the *gamcha*. Out of different types of shooting nets, the Midnapore type net with 1/8″ mesh size is found very popular and widely used.

Stake net

Modified stake nets are also being used to collect estuarine seeds without using any boats and to collect from the deeper water areas. The size of such nets is generally 7-8 m in length and 1-1.25 m width with fine mesh nylon netting cloth for smooth collections of the spawns (Fig. 3).

Scoop net

This is also known as push net and is made by triangular or double frame bamboo with zero mm mesh size mosquito net. A small size scoop net is operated single-handedly and a bigger one is often operated by two men/women (Fig. 4). Such types of net are usually operated in the shallow marginal area during both high and low tides and targeted species are prawns, shrimp, sea bass, milkfish, etc. seeds.

Fig. 2. *Meen jaal*, drag-type scoop net used for collection of *Paeneus monodon* post-larvae in Indian Sundarbans

Fig. 3. Stake net is used to collect *M. rosenbergii* seeds from the estuarine stretch of river Narmada

Fig. 4. Scoop net used to collect *M. rosenbergii* seeds from the upper estuarine stretch of river Hooghly

Dragnet

A specially designed dragnet (mesh size 1/16″) of 3 m length and 1 m width is very popular to collect post-larvae of prawns in different estuarine regions. Dragnets are usually operated by two persons near algal beds, submerged weeds and plants, and along the shallow margin of pools, where prawns seeds aggregate to take shelter. Velon screen dragnet is mainly used in the state of Tamil Nadu for the collection of prawn seeds. In the state of West Bengal, in the estuarine stretch, when the water current is too high or very feeble, dragnet was found easy to operate to collect both fin and shellfish seeds (Fig. 5).

Bundles of brushes

Bundles of brushes are mainly used to collect shellfish seeds from both current-driven areas and stagnant parts of the estuaries and rivers. Brushes are used as fish aggregating devices, and bundles of grass-shoots, paddy straw, tree branches, coir ropes, etc. are used for that (Fig. 6). Bundles of such brushes are kept in water or hung inside the water with ropes and sticks. Post-larvae of several shellfishes hide in such brushes and also aggregate in search of food, and by removing such brushes, seeds are being collected and stored for further transportation.

Bag net

Small stationary bag nets are being operated either from a bamboo fixed in the boat or from a long bamboo fixed over water surface and tied by rope from the shoreline. Nylon made zero mesh bag nets operated by boats is found very common in the Indian Sunderbans areas for the collection of *P. monodon* seeds (Fig. 7).

Cradle trap

Cradle traps are made up of muslin cloth, usually fitted with a rectangular bamboo or steel frame (1 m length and 0.75 m breadth), mainly operated to catch freshwater prawns in riverine as well as estuarine habitats. To avoid higher water current, mainly near the gates or barriers, post-larvae of prawns creep through the frame and take rest inside the cradle (Fig. 8). From time to time cradles are checked to collect the catch. Cradle traps are reported to be operated in the rivers Cauvery (John *et al.*, 1999), Mahanadi (Ahmed, 1992) and Krishna (Manna *et al.*, 2011).

Seed composition and abundance in some of the estuarine systems

The estuarine systems in India are highly potential sources of fish and prawn seeds which are generally used as the stocking materials for coastal aquaculture. In the Hooghly-Matlah estuarine systems, the most important commercial species are *Penaeus monodon*, locally known as *bagda*, followed by *P. indicus*, *Chelonplaniceps*, *C. parsia*, *Lates calcarifer*, etc. The trading of bagda seeds has been established in the lower Sundarbans areas for

Fig. 5. Collection of mullet seed using zero mesh seine net during evening hours in Saptamukhi river near Pathar Pratima, Sundarbans

Fig. 6. Dry branches of rose plants being used for collection of prawn seeds from lower stretch of river Tapti

Fig. 7. Collection of *P. monodon* post-larvae using surface set bag nets at Dhamakhali area of Sundarbans

Fig. 8. Cradle traps in operation at estuarine stretch of river Krishna for collection of *Macrobrachium malcolmsonii* post-larvae

more than 30 years, and during 1994, 1995, and 1996 the availability of *bagda* seeds in the markets were 779.66, 583.00, and 1,393.76 million in numbers during February to June months (Ayappan *et al.*, 2015). An estimated 190 million tiger prawn seeds are collected annually for stocking in *bheries* in the state of West Bengal as reported by Mandal and Bhoumik (1984).

Sambandam (1994) studied the seed resources of some of the estuarine systems in Ramnad district of Tamil Nadu and recorded *Penaeus indicus*, *P. merguiensis*, *P. semisulcatus*, *P. monodon*, *Metapenaeus monoceros*, and *M. dobsonias* the major species. De and Sinha (1997) reported that during 1985-1992, shooting net collections from the Hooghly-Matlah estuary comprised of both post-larvae of *P. monodon*, *P. indicus*, *M. brevicornis*, *M. monoceros*, *M. rude*, *M. birabile*, *P. sculptilis*, *Expalaemon styliferus*, *Acetes indicus*, and juveniles of *Chelonparsia*, *Liza* sp., *Glossogobius* sp., *Goboides* sp., *Eleutheronema tetradactylum*, *Pama pama*, *Coilia* sp., *Ambassis* sp., and crabs. Out of those, only 28-30% formed the commercially important species. The prawn and fish seed calendar for the Hooghly-Matlah estuarine system is provided in Table 1 as per the report of De and Sinha (1997).

As per Bhaumik and Mitra (2013), in the Hooghly estuary, during 1988-1994, shellfishes dominated (71.75%) the seed composition, followed by mullets (9.6%), threadfins (6.5%), *H. nehereus* (1.15%), *M. gulio* (1.1%), *T. jarbua* (0.53%), *L. calcarifer* (0.41%), *T. ilisha* (0.31%) and miscellaneous species (7.5%). In the other estuaries in India Sunderbans viz., Matla, Saptamukhi, Thakuran, Bidya, and Jheela, shellfish seed composition was 63.07-68.10% (Bhaumik and Mitra, 2013). The calendar of availability of commercially important fin and shellfish seeds in the estuaries of Indian Sunderbans is depicted in Table 2.

Table 1. *Fish and prawn seed availability calendar at Hooghly-Matlah estuarine systems (as per De and Sinha, 1997)*

Name of the species (length in mm)	Centre and month of maximum seed availability (net^{-1} hour^{-1})			Maximum seeds collected during peak months (net^{-1} hour^{-1})	
	No. of seed	Month	Centre	Max. nos. of seed (range)	Peak months of availability
Penaeus monodon (9-17)	2,332	May	Frasergunj	64-2,332	Mar-Jun
P. indicus (10-71)	8,940	Mar	Sagar	9-8,940	Feb-May
Metapenaeus brevicornis (10-45)	2,240	Jun	Frasergunj	43-2,240	Apr-Jun
M. monoceros (9-31)	1,386	May	Frasergunj	18-1,386	Apr-May/Sep
Chelon parsia (9-35)	456	Jan	Frasergunj	14-456	Jan-Apr
Macrobrachium rude (15-44)	32	Jul	Uluberia	4-32	Jul-Sep
M. mirabile (13-37)	485	Sep	Uluberia	22-485	Aug-Oct

Table 2. *Calendar of availability of commercially important fin and shellfish seeds at estuaries of Indian Sunderbans (as per Bhoumik and Mitra, 2013).*

Species	Hooghly	Matla	Saptamukhi	Thakuran	Bidya	Jheela
Penaeus monodon	May-Sep	April-Sep	May-Sep	May-Aug	Apr-Sep	Apr-Sep
Penaeus indicus	Apr-Oct	Mar-Oct	Apr-Sep	May-Oct	Jun-Aug	Jun-Jul
Macrobrachium rosenbergii	Jun-Aug	-	-	-	-	-
Chelon parsia	Mar-May	Feb-Apr	Feb-May	Feb-Mar	Jan-Feb	Jan-Feb
Chelon planiceps	Apr-Sep	Apr-Sep	Jun-Sep	Jan-Jul	May-Sep	May-Aug
Rhinomugil corsula	Jul-Aug	Jul-Aug	Jul-Aug	Jul-Sep	Jul-Oct	Jul-Oct
Lates calcarifer	Apr-Jun	May-Aug	May-Jul	May-Aug	May-Aug	May-Aug
Therapon jarbua	Apr-Sep	May-Sep	Apr-Sep	Apr-Sep	Sep-Oct	Sep-Oct
Scatophagus argus	Jun-Sep	Jun-Sep	Jun-Sep	Jul-Oct	Jul-Oct	Jul-Oct
Mystus gulio	Sep-Oct	Sep-Oct	Sep-Oct	Oct	Oct	Oct

Threats to the natural seed collectors

The collection of seeds of fishes and shellfishes involves a lot of hardship for the collectors especially for those going inside water up to waist-deep water to operate the fishing gears. Walking through the soft mud often involves injury to the foot caused by a dense molluscan population. Costal water is often habituated with ferocious animals like crocodiles or sharks. In Indian Sundarbans, death by crocodile attack is very common as observed by a survey by World Wildlife Fund (WWF) in 2006 which recorded the death of 30 persons from crocodile attacks only in three months near Bhagabatpur area of lower Sundarban. Chowdhury *et al.* (2008) reported attacks by crocodiles and sharks which mainly happened to the seed collectors in the Gosaba area of Sundarbans. Bhaumik *et al.* (2002) reported several types of diseases of seed collectors especially women in the tidal areas of Indian Sunderbans such as skin diseases, leucorrhoea, eye problem, stomach disorder, loss of body hair, weakness, problem of urination, irregularities in menstruation, palpitation and nausea, heart problem, irritation and burning sensation in the body, etc.

Conservation issues

Spawns of both fin and shellfishes are collected by the non-selective fishing gears, those are mainly made of nets with smaller mesh sizes and in certain cases with zero mesh sizes, which are found as highly destructive means of seed collection. The non-selective nets not only destruct the targeted species but also the by-catch of other non-targeted species. In many cases, by-catches have very limited uses, henceforth they are simply thrown away by the fishers and in certain places fed to the carnivorous fishes in pond aquaculture. It has been reported that fishers while collecting the seeds of targeted species like post-larvae of *Penaeus monodon*, *Macrobrachium rosenbergii*, etc. do not give enough care to the non-targeted species (Fig. 9). This resulted in disaster through the wanton killing of fish juveniles and prawn post-larvae. In the Hooghly-Matlah estuary and rivers of Sunderbans, it has been found that fishers operate both large and small size nets (shore seine) mainly to collect juveniles for stocking in coastal ponds, also called *bheri*.

A study on fin and shellfish seed availability from 40 km stretch between Kulpi and Namkhana of Hooghly estuary revealed that around 181.4 million undersized fish and shellfish seeds were destroyed during the collection of tiger prawn seeds (Bhaumik *et al.*, 1992). As per Manna *et al.* (2014) collection of juveniles of Seabass (*Lates calcarifer*), Spotted scat (*Scatophagus argus*), mullets, etc. by zero mesh dragnet create wrecking of larvae of other fishes.

Way forward

The coastal estuarine and brackish waters of the country are very important resources, as they harbor and support good quantities of brackish water species along with migratory species. Truly brackish water species such as milkfish, certain mullets, pearl spot, ladyfish, etc. fully depend on brackish water environments and migratory fishes like hilsa, prawns, etc. enter the systems for breeding and feeding purposes. In recent years, due to the increase of human interventions such as domestic and industrial pollution, expansion of brackish water fish and prawn farming, demand in the area for human settlement, industrial activities, etc., coastal brackish water areas are reducing day by

Fig. 9. Huge destruction of juvenile fishes during collection of *P. monodon* post-larvae in Hooghly estuary

day. Deforestations, destruction of mangrove forests, and reduction of catchment areas resulted in a great reduction of breeding and nursery grounds. Further, construction of dams, reduction of saline water flushing, altered freshwater flow regime, reducing the salinity gradients in the downstream of the dams, affected entry of the migratory fishes to the estuarine systems, and changed the species diversity patterns with the dominance of marine species (Manna *et al.*, 2014). Due to the increasing demands of natural seeds to meet the demands of coastal aqua farming more numbers of collectors are getting involved in seed collection ventures, which are creating overexploitation of such resources. Stopping natural seed collections with the breeding of targeted species artificially, and by providing alternative livelihoods to the natural seed collectors, might be some of the useful approaches to regenerate the estuarine fishery resources.

BIBLIOGRAPHY

Ahmed, S. M. J. (1992). Natural seed resources of freshwater prawn *M. malcolmsonii* in Orissa, *Fishing Chimes*, 19 p.

Ayyappan, S., Jena, J. K., Gopalakrishnan, A. and Pandey, A. K. (2015). Handbook of fisheries and aquaculture.

Barbosa, N. D., Rocha, R. M. and Fredou, F. L. (2012). The reproductive biology of *Plagioscion squamosissimus* (Heckel, 1840) in the Para´ River estuary (Amazon Estuary). *Journal of Applied Ichthyology*, 1-6, doi: 10.1111/j.1439-0426.2012.02040.x.

Bhaumik, U., Mitra, A., Saha, S. K. and Paria, T. (2002). Professional health hazards among the fin and shell fish collectors of Sunderbans. *Environment & Ecology* **20(3):** 514-519.

Bhaumik, U., Saha, S. and Chatterjee, J. G. (1992). Need for conservation to protect the brackish water fin-fish and shell-fish seed resources in Sundarbans. *Environment and Ecology* **10:** 919-22.

Bhoumik, U. and Mitra, A. (2013). Impact of Lunar periodicity on availability of fin and shellfish seed with special reference to *Penaeus monodon* in the estuarine systems of Sunderbans, West Bengal. *International Journal of Research and Biosciences* **2:** 63-74.

Blaber, S. J. M. (1988). Fish communities in coastal lakes (Les peuplements de poisons des poisons des lacscotieries). In: C. Leveque, M.N. Bruton and G.W. Ssentongo (Eds.), Biologie et Ecologie des Poissonsd'EauDouce (Biology and Ecology of Fish in Freshwater. In French), pp. 351-362. ORSTOM, Paris.

Bose, V. C., Venkatasan, V. and Sundabaraian, D. (1980). Prawn seed resources of Adyar Estuary at Madras. Proc. National Symp. on Shrimp Farming, Bombay, 16-18 August 1978 : 61-66.

Brinda, S., Srinivasan, M. and Balakrishnan, S. (2010). Studies on Diversity of fin fish larvae in Vellar Estuary, South east coast of India. *World Journal of Fish & Marine Sciences* **2:** 44-50.

Chao, L. N. (1986). A synopsis on zoogeography of the Sciaenidae. Pages 570-589 in Indo-Pacific Fish Biology. Uyeno, T., *et al.* (eds.). The Ichthyological Society of Japan. Tokyo.

Chowdhury, A. N., Mondal, R., Brahma, A. and Biswas, M. K. (2008). Eco-psychiatry and environmental conservation: study from Sundarban Delta, India. *Environmental Health Insights*, *2,* EHI-S935.

De, D. K. and Sinha, M. (1997). Seasonal abundance of the seed of commercially important prawns and fishes in the Hooghly-Matlah estuary during post-Farakka period. *Indian Journal of Fisheries* **44(2):** 201-209.

Gopalakrishnan, V. and Rao, R. M. (1968). Observations on the distribution of juveniles of brackish water prawns in the Hooghly and Matlah estuarine system. Proc. Sem. Prod. Quality seed fish culture, Barrackpore: 240-261.

Gopalakrishnan, V., Bhanot, K. K., Datta S. N. and Saha, S. B. (1975). Procurement of stocking material for brackishwater fish culture from the Hooghly-Matlah estuarine system. *Journal of the Inland Fisheries Society of India* **7:** 216-224.

Gopinathan, K. (1978). On the abundance and distribution of the prawn postlarvae (Penaeids) in Lake Pulicat, India. *Journal of the Inland Fisheries Society of India* **10:** 97-100.

Goswami, S. C. and Goswami, U. (1993). Seasonal variability in Penaeid Prawn larval Abundance in the Mandovi and Zuari Estuaries, Goa. *Journal of Indian Fisheries Association*, **23:** 45-54.

Jhingran, A. G. and Ghosh, K. K. (1978). The fisheries of the Ganga River System in the context of Indian aquaculture. *Aquaculture* **14(2):** 141-162. doi.org/10.1016/0044-8486(78)90026-1.

John, G., Vijayaraman, K., Sivakumar, P. and Mohamed Rafi, R. (1999). Observations on the life history and breeding behaviour of *M. malcolmsonii* of the river Cauvery, *Fishing Chimes* **18(2):** 21.

Kuttyamma, M. K. (1975). Studies on the relative abundance and seasonal variations in the occurrence of post larvae of three species of penaeid prawns in the Cochin backwaters. *Bulletin Department of Marine Science, University of Cochin*, **7:** 213-219.

Mandal, S. K. and Bhowmik, M. L. (1984). Prawn seed collection and developing seed trade in Sunderbans. *Journal of the Inland Fisheries Society of India* **16(1&2):** 51-52.

Manna, R. K., Das, A. K., Krishna Rao, D. K., Karthikeyan, M. and Singh, D. N. (2011). Fishing crafts and gear in river Krishna. *Indian Journal of Traditional Knowledge* **10(3):** 491-497.

Manna, R. K., Roshith, C. M., Das, S. K., Suresh, V. R. and Sharma, A. P. (2014). Salinity regime and fish species distribution in the Hooghly-Matlah estuary. In: Sinha R. K. and Ahmed, B. (eds.). River for Life- Proceedings of the International Symposium on River Biodiversity: Ganges-Brahmaputra-Meghna River System. IUCN, 232-240 pp.

Ramamurthy, S. (1982). Prawn seed resource of the estuaries in the Mangalore area. Proceedings of the Symposium on Coastal Aquaculture, **1:** 160- 172.

Sambandam, K. P. (1994). A comparative study of prawn seed resources of estuaries in Ramnad district, Tamilnadu. *Journal of Marine Biological Association of India*, **36(1&2):** 57-62.

Sambandam, K. P., Lawrence, L. and Noble, J. (1982). Some observations on penaeid prawn seed resources in the Vellar estuarine system (Porto Novo). In: *Proceedings of the Symposium on Coastal Aquaculture*, **1:** 308-313.

Silambarasan, K., Mariacharles, P., Velmurugan, K., Rajalakshmi, E. and Senthilkumar, P. (2013). Esturaine *Penaeus indicus* seed potentials for aquaculture in Tamil Nadu. *International Journal of Recent Scientific Research*, **4(12):** 2126-2130.

Sugunan, V. V. (2010). Inland Fisheries Resource enhancement and conservation in India. In: *Inland fisheries resource enhancement and conservation in Asia*, (*eds.*) Weimin, M., Silva, S.D. and Davy, B., RAP Publication 2010/22, pp. 35-60.

Victors, C. and Venkatesan, V. (1982). Prawn and fish seed resources of Merakanam estuary. In Proc. *Symp. Coastal Aquaculture*, pp. 196-201.

Wallace J. H. (1975a). The estuarine fishes of the east coast of South Africa. Part III. Reproduction. *Invest. Rep. Oceanogr. Res. Inst.* (*Durban*), No. 41. 48 pp.

Wallace J. H. (1975b). The estuarine fishes of the east coast of South Africa. Part I. Species composition and length distribution in the estuarine and marine environments. Part II. Seasonal abundance and migrations. *Invest. Rep. Oceanogr. Res. Inst*. (*Durban*), No. 40. 72 pp.

Brackishwater Aquaculture Management in Coastal Ecosystem

T. K. GHOSHAL*, DEBASIS DE, SANJOY DAS, PREM KUMAR and CHRISTINA L

Kakdwip Research Centre of ICAR-CIBA, Kakdwip, South 24 Parganas, W.B. – 743347, India

**Corresponding author:* E-mail: ghosalciba@gmail.com

Aquaculture in India has evolved as a viable commercial farming practice from the level of traditionally backyard activity over last three decades with considerable diversification in terms of species and systems, and has been showing an impressive annual growth rate of 6-7 percent. Coastal aquaculture emerged as a sunrise sector in India during the 1990s. Besides supply of high quality protein for domestic consumption, it has also been identified as a sector with full of promise for expanding exports and for adding to foreign exchange.

Indian brackishwater aquaculture comprising of shell-fish and finfish farming is an economic engine in the Indian aquafarming sector. At present, India is a major shrimp producing nation in the Asian region with an export of nearly 14 lakh MT of seafood valued at ₹45 thousand crore. Frozen shrimp maintained its position as the key contributor to seafood export basket, accounting for more than 40% in quantity and 68% of the total export earnings. Shrimp exports during 2018-19 rose by 30.26% in quantity and 30.10% in dollar terms compared to preceding financial year. Frozen fish, the second largest export item, contributed 25.64% in quantity and 10.35% in earnings. The aquaculture sector of India witnessed a boom with the introduction of white leg shrimps (*Penaeus vannamei*) since 2009-10. Increased sustainable production of Pacific white shrimp, diversification of aquaculture with native species, sustained measures to ensure quality, and increase in infrastructure facilities for production of value added products have been largely responsible for India's positive growth in exports of seafood.

Brackishwater farming in India is an age-old traditional system confined mainly to the 'bheries' (manmade impoundments in coastal wetlands) of West Bengal, 'gheris' in Odisha, 'pokkali' (salt resistant deep water paddy) fields in Kerala, 'khar lands' in Karnataka and 'khazans' in Goa coasts. These systems have been sustaining production of 500-750 kg ha^{-1} year^{-1} with shrimp contributing 20-25% with no additional input, except that of trapping the naturally bred juvenile fish and shrimp seed during tidal influx.

The age old traditional farming methods of fin fish and shrimp with some modification still exist because of their simplicity and cheapness. These are being gradually replaced by modern improved culture practices. Commercial shrimp farming with tiger shrimp, *Penaeus monodonin* India started gaining roots only during the mid-eighties. The boom period of commercial-scale shrimp culture started in 1990 and the bust came in 1995-96, with the outbreak of viral disease. Later with the advent of bio-secured closed culture technology using better management practices, semi-intensive shrimp farming started to regain its lost glory during early years of this century. This system involves no water exchange, disinfection of pond by chlorination, use of PCR tested disease free hatchery produced seeds, strict feeding schedule, use of pre and probiotics and proper pond and shrimp health management. Following this method farmers are getting production at the range of 4-6 tonnes ha^{-1}. In early nineties shrimp farming was low risk and high profit venture, however the present form of shrimp farming has become low profit and high risk venture. The reasons behind decreasing profitability are abnormal hike in the input cost and decreasing trend in the sale price of the product.

Viewing the disease risks associated with tiger shrimp farming and decreasing profitability, farmers have felt the need of diversification to secure income and sustainability in very recent years. The Coastal Aquaculture Authority of India (CAA) permitted introduction of *Penaeus vannamei* (Pacific white leg shrimp) in India during 2009 with prescribed guidelines. Before introduction, risk analysis was carried out by ICAR-Central Institute of Brackishwater Aquaculture (ICAR-CIBA) and National Bureau for Fish Genetic Resources (ICAR-NBFGR) after pilot scale initiation in 2003. Since introduction, *P.vannamei* farming showed rapid growth and a shift towards *P.vannamei* from *P. monodon* was observed.

Accidental releases of non-native species into natural waters are common and can represent impacts in the environment and biodiversity, and a serious risk of transmission of pathogens. Feeling the importance of domestication of potential native shrimp species in addition to tiger shrimp, Indian white shrimp (*Penaeus indicus*) has been domesticated by ICAR-CIBA and its experimental farming showed encouraging results with production of 3-5 tons per ha.

In spite of having huge potential for mud crab farming and export, still there is no organized farming to support the export trade mainly due to inconsistent availability of seeds. Technology for seed production, culture and fattening of green mud crab *Scyllla serrata* has been developed by CIBA. After the inception of crab hatchery by the Rajiv Gandhi Centre for Aquaculture (RGCA) in Tamil Nadu, some progressive farmers have started crab grow-out farming in the country using hatchery produced seeds.

High value fishes like Asian seabass (*Lates calcarifer*), Grey mullet (*Mugil cephalus*), Tade mullet (*Liza tade*), Parsia (*Liza parsia*), Nona tangra (*Mystusgulio*), Milkfish (*Chanos chanos*), Pearlspot (*Etroplus suratensis*) and Cobia (*Rachycentron canadam*) are available for farming. Successful technology has been developed for the seed production of Asian seabass, Grey mullet, Milkfish, Pearlspot, Cobia and Nona tangra under controlled conditions and farming by ICAR-CIBA. All those fishes have shown promises for commercial aquaculture in inland saline soil/water areas with production ranging from 0.5 to 4 tons/ hectare/ year.

Shrimp farming Practices

Different commercially important shrimp species are as follows:

Penaeus vannamei (White-legged shrimp)

- Captured wild seeds were used in Latin America for extensive pond culture of *P. vannamei* until the late 1990s.
- Domestication and genetic selection programmes provided more consistent supplies of high quality, disease free and/or resistant PL (postlarvae) which were cultured in hatcheries.
- Culture period: 90-120 days, body weight at harvest: 25-35g

Penaeus monodon (Tiger-shrimp)

- Penaeus monodon mature and breed only in tropical marine habitats and spend their larval, juvenile, adolescent and sub-adult stages in coastal estuaries, lagoons or mangrove areas.
- In the wild, they show marked nocturnal activity, burrowing into bottom substratum during the day and emerging at night to search for food as benthic feeders.
- Under natural conditions, the giant tiger prawn is more of a predator than an omnivorous scavenger or detritus feeder than other penaeid shrimp
- Availability: Both east coast and west coasts of India and Andaman waters
- Culture period: 120-150 days, body weight at harvest: 30-40g

Penaeus indicus (Indian White Shrimp)

- Hatchery technology and initial trials on domestication carried out during 1980 in India
- Breeding and culture trial has been carried out at CIBA
- Is not a natural host of many emerging diseases
- Genetically distinct population and scope for genetic improvement

- Strong osmoregulation and can be cultivated under wide range of salinity
- Availability: Both east coast and west coasts of India
- Culture period: 90-120 days, body weight at harvest: 20-30g

Penaeus japonicus (Kuruma shrimp)

- Successfully domesticated
- Requires high protein
- High salinity for culture
- Highly favourable in Japan and success in genetic improvement programme was achieved in Australia and Japan
- Availability: Gujarat, Tamil Nadu, Maharashtra
- Culture period: 90-120 days, body weight at harvest: 30-40g

Penaeus merguensis (Banana shrimp)

- Reach full ovarian maturation under captivity
- Can mature and spawn without eyestalk ablation
- Attains commercial size within 130 days
- Require less protein
- Availability: Both east coast and west coasts of India and Andaman waters
- Culture period: 90-120 days, body weight at harvest: 20-25g.

Shrimp culture practices

Most common shrimp farming practices followed in West Bengal are traditional, extensive, semi-intensive and intensive. These four categories are divided, according to their stocking densities (shrimp m^{-2}), and the extent of management over grow-out parameters, *i.e.* level of inputs (Table 1).

Traditional brackishwater aquaculture practices dependent completely on the natural tidal entry of seed and food through water exchange. Furthermore, traditional systems are often characterized by polyculture with fish or by rotation with rice. In this method, low lying areas near the banks of saline water rivers and creeks are encircled by peripheral dyke and tidal water is allowed to enter in the impoundment along with natural seeds of various species of shrimps, crabs and fishes. Water is retained with periodical exchanges during lunar cycles and the animals are allowed to grow. After 3-4 months harvesting is done partially during lunar cycles. Productivity in this system ranges between 500-750 kg perha of which about 30 percent is constituted by prawns/ shrimps and 70 per cent by fishes.

Table 1: *Farming practices based on level of management, stocking density and production*

	Traditional	Extensive	Semi-intensive	Intensive
Pond size (ha)	0.1-50	1-10	0.2-2	0.1-1
Stocking	Natural	Natural +artificial	Artificial	Artificial
Stocking density (seed m^{-2})	Unregulated	2-6	6-20	20-60
Annual production (t $ha^{-1}yr^{-1}$)	< 0.6	0.6-1.5	2-6	7-15
Feed source	Natural	Natural	Natural +Formulated	Formulated
Aeration	No	No	Yes	Yes
Diversity of crops	Polyculture	Mono/polyculture	Monoculture	Monoculture

Extensive shrimp aquaculture is primarily used in areas with limited infrastructure. Producers rely on the tides to provide most of the food for the shrimp and as a means of water exchange. Feed for shrimp is naturally occurring, in some cases fertilizers or manure is added to promote algal growth. Low stocking densities result in modest yields. Land and labour are the principal inputs, which keeps operational cost at a minimum. This system involves construction of peripheral canals/ ponds of size ranging from 1-5 ha. Native shrimp seed are stocked at the rate of 15000-20000 ha^{-1}. Water management is done by tidal effect. The average yield is 1500-1700 kg ha^{-1}, including fin fishes. In most of the cases the stock is left at the mercy of nature and the predators. Supplementary feeding is not generally practiced as the entire production system is dependent on utilization of natural productivities. However some farmers use oilcakes and rice bran to increase production.

Semi-intensive and intensive farming involves stocking densities beyond those that the natural environment can sustain. Consequently these systems depend on a reliable shrimp post larvae (PL) supply, and a greater management intervention in the pond's operation compared to extensive ponds. Following are the steps involved in semi-intensive and intensive shrimp farming:

Site selection: The site is selected only after thorough analysis of information on topography, ecosystem, meteorological and socioeconomic conditions and economic viability. Coastal sites with gentle slopes towards the sea are selected requiring less financial inputs. Clay-loam or silty-clay loam soil is preferred. Site should be easily accessible with availability of basic needs.

Farm design and construction: Proper designing and construction of farms are essential for efficient management and for promoting environmental protection. The height of peripheral dyke is built in accordance with highest flood level. Height of the pond dyke should be at least 2 m with slope of 1:1 for clayey soil and 3:1 for sandy soil. Rectangular or square ponds are appropriate. A reservoir pond is required to act as settlement pond. Effluent treatment pond (ETP) becomes an essential part of a semi-intensive farm.

Pond preparation: Good pond preparation is the key to reduce disease risks and improving shrimp production. Presence of black soil in pond bottom is checked in wet condition. Black soil is removed either using mud pumps in wet condition or manual labor after drying. Optimum average soil pH is 6.5-7.5 whereas optimum pond water pH is 7.5-8.5 Lower soil pH is corrected by applying lime. Soon after pH correction, ponds are filled with optimum quality water upto a depth of 130-150 cm after screening through 60-80 mesh net. Water is retained for 3 days with daily 1-3 hoursof aeration. Aerators should be positioned properly to achieve maximum water circulation. For every 500 kg shrimp production beyond 2000 kg ha^{-1} requires minimum 1 KW aeration power. Pond water is disinfected by applying bleaching powder @ 60 ppm (20 ppm chlorine) during late evening. After 5 days, dolomite @ 100-200 kg ha^{-1} and organic juice @ 200 litre ha^{-1} on the following day is applied to stimulate the plankton bloom. This schedule is repeated three times at a gap of 3 days. Organic juice is prepared by mixing 60 kg paddy flour, 20 kg molasses and 3 kg yeast in 200 L freshwater per ha and incubated for 48 hours in air tight condition. When the color of the water is green/ brownish green, fluctuation between morning (6:00 AM) and late afternoon (3:00 PM) pH is below 0.5 and other parameters in optimum range, the pond is ready for stocking seeds.

Biosecurity measures: Biosecurity measures are of immense importance in shrimp farming to protect the stock from diseases. Farms must establish adequate bio-security measures including crab fencing, bird-fencing, reservoirs, separate implements for each ponds etc. The farms should be managed by the personnel who are trained and/ or experienced in management of bio-security measures.Proper hand and foot wash in potassium permanganate solution is mandatory before entering the farm. Depth more than 120 cm reduces stress and risks of diseases. Farming in closed ponds i.e. '0 exchange' restricts entry of pathogen and carriers of diseases. All utilities are washed in chlorinated water before first use. Proper understanding of personals about biosecurity is most important.

Seed Stocking: Good quality, PCR tested post larvae (PL) from authorized hatcheries should be stocked. Good quality seeds are of uniform size, light gray or brown in colour and with good activity. Stocking is done during early morning or late night after proper acclimatization. Shrimp should be acclimatized gradually to pond salinity, temperature and pH by floating and splashing water in the seed packet before stocking. The duration of acclimatization depends on the difference in these parameters.Recommended stocking density is up to 25 numbers/ sq m for *P. monodon* and up to 60 numbers/ sq m for *P. vannamei* and *P. indicus*.

Pond bottom soil removal

Bird fencing

Crab fencing

Seed acclimatization in pond

Post-harvest pond management

The effluent from shrimp culture pond post-harvest has high concentration of nutrients, suspended solids and metabolites than the water bodies into which they are discharge. Quantitative comparisons of shrimp farm influent and effluent water have demonstrated that effluent can contain elevated concentrations of dissolved nutrients, phytoplankton, bacteria and other suspended organic and inorganic solids. The effluent discharge of shrimp culture ponds must be in compliance with effluents permits and standards of regulation provided by the organizations (Coastal Aquaculture Authority, Govt. of India). The procedure by which a certain admissible level that has to be achieved are usually not a mandate and therefore different types of mechanisms may be employed for better quality effluent.

The effluent treatment system (ETP) is mandatory for farms above 5 ha for Penaeus *monodon* farming. In case of *Penaeus vannamei* culture, ETS is mandatory for all farms irrespective of the size when they follow the stocking density of upto 60 nos per sq.m as provided by the Coastal Aquaculture Authority (CAA) guidelines (Table 2). In low density culture of *L. vannamei* (20 nos. per sq.m), ETS is left optional for farms of less than 5 ha. Since ETS is optional on account of low stocking density, in order to prevent escapes into natural environment harvesting shall be done only through drag netting. Sedimentation of water should be carried out at least for three days for settlement of suspended particles and disinfected before release (CAA, 2010). The ETP may consist of:

- *Sedimentation pond:* Sedimentation is very useful in reducing total suspended solids (TSS) but it is less effective in reducing nutrients concentration. When the water is discharge without sedimentation, the drainage canal may serves as a settling basin for the pond's effluent water. Bivalves which are often used in bio-treatment ponds assimilate the nutrients present in water better after sedimentation. It therefore requires an integrated approach involving treatments using biological or chemical means to improve the quality of the discharge water.

- *Bio-pond and aeration pond:* Biological treatment aims at using plants, macrophytes, bivalves etc. to reduce the nutrient load and particulate matter in shrimp farm dishcharge. Seaweeds such as Kappaphycus, Gracilaria, Ulva etc., and bivalves such as oysters and mussels are commonly used for treating shrimp farm effluents. The combined biofiltration effect of the oyster and algae can result in decrease in turbidity, nutrients, TSS and metabolites and can be used effectively in coastal areas where salinity is high. Aeration will help in oxidizing the leftover ammonia and increased DO (dissolved oxygen) in the water.

Mud crab grow-out culture and fattening practices

In India, mud crabs (Green crab, *Scylla serrata* and orangs mud crab, *Scylla olivacea*) are utilized for local consumption and export trade in the form of frozen and canned meat. Recently, the export of live mud crab has gained importance. To meet the ever increasing demand for live mud crabs, mud crabs collected from wild are now being cultured or fattened on a small scale in the maritime states like Andhra Pradesh, Kerala, Karnataka, Orissa, Tamil Nadu and West Bengal.

Table 2: *Parameters of water discharged from the aquaculture farms, hatcheries (CAA, 2006)*

Sl. No.	Parameters	Final discharge point	
		Coastal Marine waters	Creek or estuarine courses when the same inland water courses are used as water source and disposal point
1.	pH	6.0- 8.5	6.0-8.5
2.	Suspended solids mg l^{-1}	100	Not less than 3
3.	Dissolved oxygen mg l^{-1}	Not less than 3	Not less than 3
4.	Free Ammonia (as NH_3-N) mg l^{-1}	1.0	0.5
5.	Biochemical Oxygen Demand- BOD (5days @ 20ºC) max mg l^{-1}	50	20
6.	Chemical Oxygen Demand –COD mg l^{-1} max	100	75
7.	Dissolved phosphate (as P) mg l^{-1} max	0.4	0.2
8.	Total nitrogen (as N) mg l^{-1}	2.0	2.0

2HP paddle wheel aerator

Inspection of check tray in shrimp pond

Mud crab grow-out culture:

Mud crab is generally cultured in grow out ponds as monoculture with single crab species orin polyculture system with other fish species such as mullet (*Mugilcephalus*) and shrimp. For grow-out culture, crab juveniles of 25-50 gm body weight are stocked at a density of 0.5-1 no. per sq m in fenced earthen pond or cement tanks. Feeding is done twice daily with trash fish or combination of trash fish and molluscan meat at therate 4-8% body weight. Sufficient hide outs in the form of plastic pipes, damaged vehicle tyres, cement pipes are provided at pond bottom to prevent cannibalism. After 6-8 months of culture, 1-2 ton per ha crab is harvested.

Mud crab fattening practices:

Mud crab fattening carried out by fisherwoman is an eye-opener in the context of providing opportunities for a socio-economically viable avocation for coastal rural women. During shrimp farming this was considered as a menace. But now it has been realized that it is a blessing in disguise as an alternative species due to set backs in shrimp farming and the technology up gradation.Water crabs are not accepted in live crab export tradeand rejected in the export market as water crabs are weak with less meat.To have full growth of meat and to gain weight, crab fattening with export rejected water crabs are practicedby coastal men and women self- help groups as an alternative livelihood option. Crab fattening is essentially a holding operation during which post molt or water crabs are kept for a short period of 20 days until they flesh out or immature female crabs are held until their gonads develop and fill the mantle cavity. This type of activity has become very popular throughout the Asian countries due to increasing demand for gravid females and large size hard shelled ones in seafood restaurants.

Mud crab fattening in FRP cages/boxes:

The process of crab fattening by the cage method requires an area of 100 sq.ft. Initially the avenue can be started as experimental basis. The crab fattening needs a proper water management through the tidal exchange, feeding schedule and timely feeding should be followed. Unlike shrimp farming which needs a higher capital investment, the mud crab fattening process can be carried out with less finance.

Fiber glass cages either with 6 or 9 compartments can be used or fibre made boxes can be used. Each compartment/ boxes can be stocked with one crab each weighing 500g-700g. The four sides of the cages should be well perforated for free circulation of water. Each compartment should measures about 1m×1m×0.33m. The four sides of the cages should be perforated for free circulation of water. The culture period is 3-4 weeks. Feeds like trash fish or formulated feeds can be given. The fattening duration is about 20-25 days. The cages should be checked from the 10^{th} day of stocking for the hard crabs. If hard crabs were found, they should be harvested from 10^{th} day onwards and up to 25 days. The survival is excellent (99%) and the total biomass harvested from 8 cages can be 54 kg.

Periodical checking should be done during the culture period. After use, the cages are dried and cleaned for next round of use. Trash fishes collected from the landing centers are fed @ of 10% of the biomass of the crab at two intervals (morning and evening) every day. In case of algal and barnacle fouling on the crab carapace, they should be removed by brushing. During fattening, the water temperature should ranges between 25°C and 30°C, the pH value between 7.5 and 8.5, salinity 5-40 ppt and the dissolved oxygen >4 ppm. The harvesting of the fattened crabs can be carried out by hand picking.

Mud crab fattening in pens:

Crab fattening can also be carried out in small pens with fence around ranging from 0.1 to 0.5 ha in size with water depth of 1.5 m. Fencing with height of 0.5-1.0 m is done with nylon materials. Materials like bamboo pieces, cement pipes or stones as hiding places can be placed inside the pond to minimize mortality due to cannibalism. The tidal water flood through the creek causes sufficient water exchange in the pens. The soft shelled crab of more than 100 g can be stocked at the density of 1 crab per m^2. Crabs can be fed with bivalve meat or trash fish daily at the rate of 5 to 10% of body weight. The duration of fattening is 20 days.

The crabs can be harvested after the shells becomes sufficiently hardened and before next molting. The harvesting can be done by using scoop nets and ring nets with baits. Harvesting should be done in the early morning hours or evening to prevent mortality of crabs due to overheating of water at noon time. In a year 9 to 10 cycles of fattening can be taken from a pond.

Marketing of mud crabs

Generally the mud crabs are marketed and sold in live condition. The first pair of largest legs (chelate legs) of each live crab is firmly tied up with the body by jute/ nylon thread to curb their movement and to avoid fighting among them. The bulk of the catch is usually packed in bamboo baskets. Wet seaweed is placed in the baskets to keep the live crabs cool and moist. The baskets – packed crabs are transported from the site to the major cities by road or rail and sold through the middlemen to retailers. For live crabs export trade, the leg tied-up mud crabs should be washed with seawater and packed either in bamboo baskets covered with plastic sheets in the bottom or perforated thermocol boxes.

Fin-fish culture practices:

Asian seabass (*Lates calcarifer*)

The Asian seabass *Lates calcarifer* commonly known as bhetki in India is one of the most preferred candidate species for brackishwater aquaculture. Seed availability from the natural water bodies has been reported from all most all coastal states of India from April to September. It is a euryhaline fish capable of withstanding wide environmental fluctuations and can be farmed in brackishwater, seawater and freshwater environment in different culture systems (cage, pond and tank). Seed production technology, feed and culture methodology of seabass is developed and demonstrated by ICAR-Central Institute of Brackishwater Aquaculture (CIBA). To reduce the farming duration, CIBA has also developed innovative culture technology through splitting the culture phases into 3 components; 1) nursery, 2) pre-grow out and 3) grow-out phases. In the nursery phase, hatchery reared fry are reared either in hapa, tank or pond (250-300 nos. perm3) and fed with formulated feed/ minced meat/farm made feed/ Artemia biomass for a period of 45-50 days and subsequently transferred to pre-grow out ponds/cages (8-10 nos.per m^3) and reared for a period of 3 months or till they attain a size of 80-100 g. These pre-grow out juveniles are cultured in grow-out ponds for a period of 8-10 months and fed with formulated feed having crude protein content of 45% or / low cost fish. Production up to 4-5 tonper ha with the FCR (Feed Conversion Ratio) of 1.6-1.8 in 6-8 months of culture period can be achieved with a viable profit.

Nursery rearing:

In the nursery phase, hatchery reared fry are reared either in hapa, tank or pond (250-300 nos. m^{-3}) and fed with formulated feed (45-48% protein)/ minced meat/farm made feed/ Artemia biomass to the *ad libitum* for 3-4 times daily for a period of 45-50 days. In tank based nursery rearing, 25 days old seabass fry in the size range of 1.0-1.5 cm is stock @ 1000 no m^{-3} in nursery tanks (5-10 t). After 45-60 days rearing with flow through facility and frequent grading, the fry reach to fingerling size (7-8 cm) with an survival range of 53-65%. In nursery rearing in net cage hapa (1×2×1 m) seabass fry is stock @250-300nos. m^{-3} in the hapa fixed in the pond. In the nursery rearing in net cage hapas in a period of 45-55 days the seed attain size of 7-8 cm with survival rate of 60-70%. For nursery rearing in pond, small nursery pond of 10×10 or 10×15 m is desirable. During pond preparation drying, liming, manuring (cow dung @200kg $100m^{-2}$) is done, 10 days before the stocking of fry. In these ponds hatchery produced seabass fry of 1.0-1.5 cm are stocked @20-30 m^{-2}. Fish are also fed with zooplankton, small crustaceans (*Azetes*, *Mysids*) collected from adjoining canals or ponds. After rearing period of 20-25 days fingerlings of 25-30 cm are harvested with survival rate of 70-80%. Since, seabass exhibits cannibalistic behaviour (*i.e.* the large prey up on the smaller siblings), it is necessary to keep more or less uniform size through regular grading. Grading (segregating size wise using smaller size sieves manually or by automatic graders) at interval of 3-4 days is essentially required.

Pre-grow out rearing:

Pre-grow out is performed to reduce the final culture duration of seabass. During pre-growout, fingerlings are stock @ 8-10 nos. M^{-3} and reared for a period of 3 months or till they attain a size of 80-100 g. During this period fishes are fed with formulated pellet or trash fish. At the end of 3 months, survival rate of 60-70%, the average size of 100-120 gms is obtained.

Traditional farming:

Farming of seabass is practiced in the traditional ponds in coastal area. The juvenile, entering in to the estuaries and backwater are allowed to enter or collected and stocked in the ponds. This natural collected seabass feed on small fishes and crustaceans entering along with tidal waters and attain size varying from 0.25-2.0 kg over a period of 6-8 months. In other way of traditional farming seabass is co-culture with tilapia. In this farming system, forage fishes like Tilapia of different size, which are prolific in breeding are stocked @ of 5000-8000 ha^{-1} and along with this seabass collected from the wild are stocked @ 8000-10000 ha^{-1}. The seabass initially feed on smaller Tilapia later on larger ones. As and when the population is reduced, tilapia is againintroduced. Some farmers resort to feeding with low cost fishes procured from the sea catches or from pond. These types of farming are practiced traditionally. These methods of farming may be feasible where low cost fishes are abundantly available in the vicinity of the culture site.

Improved farming:

When juveniles are stocked, the stocking density is maintained around 7000-8000nos. ha-1 and with the culture duration of 6-7 months, the fish attain size of 800 -900 gms with survival rate of 80-85%. The yield will be 5.12-5.35 tons ha^{-1}. Farming can be done both by feeding with low cost fishes (wherever easily available) and with formulated feed. CIBA has developed feed for seabass (*BhetkiAahar*) culture. Farming of seabass in re-circulatory aquaculture system (RAS) is commercially viable.

Milkfish (*Chanos chanos*)

Milkfish, *Chanos chanos* belongs to the order Gonorynchiformes and is the only live species of the family Chanidae. It is a euryhaline, herbivorous, fish which is widely distributed in Indo-Pacific region but abundantly in Philippines and Indonesia. The fish can be farmed in brackishwater and freshwater ponds, pens and cages. Milkfish farming is being practiced traditionally in certain parts of India by stocking the wild seed along with other species such as mullets, seabass, shrimp etc. in polyculture mode. Milkfish seed availability has been reported in many places especially on the east coast of India from Vishakhapatnam to Rameswaram and Krusadai islands in Tamil Nadu. In general, milkfish fry is available extensively during March to May in places such as Rameswaram and Pamban coastal back waters of Tamil Nadu and Narzapur coastal waters of East Godavary District, Andhra Pradesh. Milkfish nursery and

farming is need '*lablab*', which comprises mainly of cyanobacteria, filamentous green algae, copepods and detritus. Milkfish fetches good price in national and international markets. Generally, in the domestic market of India milkfish fetches 150-200 INR kg^{-1} at farm-gate while cost of farm production is 90-100 INR kg^{-1}.

Nursery rearing

Milkfish fry (2-2.5 cm) is stock at a density of up to 20-30 no. m^{-2} (2-3 lakhs ha^{-1}) in nursery ponds and are allowed to feed on naturally-grown micro benthic food complex known as '*lablab*'. Supplementary feed is also provided during nursery rearing. Urea and single super phosphate both at the rate of 20 kg ha^{-1} can be applied fortnightly to maintain good growth of natural food and lablab. After 4-5 months of nursery milkfish fry attain the size of 5-8 cm (fingerling).

Traditional farming

In India, milkfish traditional farming is done in different traditional brackishwater areas like Bheries in West Bengal, Gheries of Chilka Lake in Odisha, *Pokkali* in Kerala, *Kharlands* in Karnataka and *Khazans* in Goa from wild seed. In this traditional farming, milkfish mainly feeds on natural food like *lablab* (benthic algae) and *lumut* (filamentous algae). In this farming system, production ranged from 750 kg to 1200 Kg ha^{-1} $year^{-1}$.

Semi-intensive pond farming

In this type of farming, nursery reared milkfish fingerlings of 7-15 cm size is stock @ 8000-10,000 ha^{-1} and fed with formulated grow-out floating feed (CP 24-28%, CF 3-4%) @ 2-3% of body weight. Periodical manuring is suggested to facilitate the growth of natural phytoplankton and zooplankton in the system. In 4-6 months, fish attain 400-500 g body weight and with average production of 3.5- 4 ton ha^{-1}.

Recent culture trials in Sundarbans by Kakdwip Research Centre of CIBA at stocking density of 1 fish per m^2 and feeding with formulated floating pellet feed (Crude Protein: 24%, Crude fat: 4%) @ 6-2% of fish biomass in non-aerated periphyton supported brackishwater pond has achieved production of more than 4 tons per ha in 8 months. Fishes grew to 400-500 g during 8 months rearing period registering over 90% survival. This fish is a good candidate species for polyculture with shrimp as it has stronger mucosal immune properties.

Brackishwater catfish (*Mystus gulio*)

The long whiskers catfish, *Mystus gulio* (Hamilton, 1822), is a euryhaline fish commonly known as nuna-tengra in West Bengal. Due to euryhaline nature this fish can be farmed in both freshwater and brackishwater environment. This fish is one of the most preferred fish due to delicious taste and medicinal value, therefore it has high consumer preference and market demand in eastern India. It is a small indigenous fish species (SIS), contains high nutritional value in terms of protein, micronutrients, vitamins and minerals. *M. guliois* traditionally farmed in rice fields and brackishwater areas of eastern India (West Bengal). It is an important cultivable fish in paddy fields and *bheris* of the Sunderban. Kakdwip Research Centre of ICAR-CIBA has developed and popularised a cost effective, farmer-friendly Homestead Modular Hatchery Technology (HMHT) and farming of *M. gulio*.

Nursery rearing:

Nursery rearing is required to produce stockable sized seed for farming. Nursery rearing of M. guliolarvae is carried out either in net cage hapa, tanks or small ponds. Nursery rearing in net cage hapa for 60 days produces stockable size fry. In this system, 7-10 days old larvae (0.01-0.02 g) are reared in in hapa (2×1×1m) at an ideal density of 500 larvae/ hapa. During hapa nursery larvae are fed four times daily with larval feed at the rate of 10% of total biomass. After 60 days of rearing, larvae attain around 1.30-1.50 g weight with the survival of 45-50%.

Culture technique:

Ponds are prepared following the standard operating procedure of drying (7-10 days), liming (agriculture lime @ 200-250 kg ha-1), water filling, chlorination (bleaching powder @ 500 kg ha^{-1}), dechlorination (7-10 days) and fertilisation. Fertilization is done 7-10 days after cholorination with organic and inorganic fertilisers. Mustard oil cake, urea, and single super phosphate are applied at the rate of 250, 50, and 50 kg ha^{-1}, respectively. Farmers also practice the application of fermented 'juice' made up of molasses 8-10 kg, probiotic-50 g, wet yeast-100 g, rice bran-1 kg, mustard oil cake-5 kg and water-200 litres. This juice is kept for fermentation in a tank covered with polythene for 2-3 days. The juice is applied at fort night interval or whenever needed. Nursery-reared fry of 30-35 days age are stocked at a density of 10 fry m^{-2}. Either floating or sinking feed having a protein content of 28-30% is fed at the rate of 5-8% of body weight. In six months of culture, fish attain an average marketable size of 50 to 60 g with the production of 1.2 to 2.4 tonnes ha^{-1}. The cost of production comes in around Rs. 60-80 / kg and it has a ready market price of a minimum of ₹250-500 kg^{-1}. High-density farming (stocking density: 10-20 fish m^{-2}) in RAS and polythene-lined small backyard ponds (stocking density: 300 to 500 m^{-2}) is also recommended.

Grey Mullet, *Mugil cephalus*

Mullet species can be farmed in polyculture with other compatible species as well as monoculture in brackishwater systems. Natural backwater of Kerala and Tamil Nadu are important source of mullet seed. In West Bengal, juvenile minor mullet seed such as *Liza parsia* and *Lizatade* are available in large numbers especially in the Sundarban estuarine waters. Among the different species of mullet, *M. cephalus* has rapid growth rate. However, naturally available seed is a mixture of many species. Full-scale commercial production of grey mullet (*Mugil cephalus*) is a new area of aquaculture diversification in India.

Nursery rearing

Wild collected seed is nursery reared in earthen pond at the stocking density of $25m^{-2}$ for a period of 4-6 months or till attain the size of 20-30 g. Well prepared earthen pond with the provision of periphyton substrate is suitable for mullet nursery rearing.

Farming

Grey mullets are usually grown in monoculture or polyculture ponds. Prior to stocking, ponds are prepared by drying, ploughing, and manuring with 2.5-5.0 tonnes per ha of cowdung. Ponds are then filled to a depth of 25-30 cm and kept at that level for 7-10 days to build up a suitable level of natural feed. The water level is then increased to 1.5-1.75 m and fingerlings are stocked @ 1-2 m^{-2}. Extruded feed is supplied to semi-intensive ponds @ 3-5% of fish biomass. The growing season is normally about 7-8 months. A production of 2.3-3.7 tons ha^{-1} can be achieved. In polyculture, they are usually stocked with tilapia, milkfish and pearl-spot in brackishwater, and with common carp and silver carp in freshwater. In this case, feeding and fertilization programmes are usually targeting the other cultured species, and the mullet feed on the natural feed, detritus, and feed leftovers. Acclimatized to the appropriate salinity, and stocked as 10-15 g individuals at 0.6-0.7 per m^2, a harvest of 4.3-5.6 per tonnes ha^{-1} $crop^{-1}$ can be obtained.

Feeding management in brackishwater aquaculture

Feeding management of fish:

Feed is a major input in brackishwater aquafarming contributing 60-70% of operational expenses and feeding is most important and crucial for viability and success in aquaculture.Optimal feeding rate and frequency are essential in maximizing conversion rate of feed and avoid overfeedingFollowing points should be strictly followed while feeding the fish for maintaining good pond hygiene and to reduce wastage of feed and to avoid accumulation in pond bottom.

1. Pond biomass estimation: Pond biomass should be assessed regularly and ration size should be determined as per biomass of the pond.
2. Number of times organism should be fed in a day *i.e.*, frequency of feeding
3. When feed should be offered *i.e.* time of feeding
4. The way feed should be offered in the system *i.e.*, method of feeding.

Ration size:

Ration size is the allotted feed quantity for the cultured species for the period of 24 hours. Ration size may vary depending on life stages of fish.Young fish require bigger ration size. The quantity of ration varies from 100% of body weight for larvae and fry and gradually reduced to 50%, 20%, 10%, 5% and 2-3% as the fish/shrimp grow marketable size. Generally the method of calculating the daily ration is based on the body weight of fish.

$$\text{Ration size (Kg)} = \frac{\text{ABW(g)} \times \text{Stocked nos.} \times \text{Survival(\%)} \times \text{Rate of feeding(\%)} \times 1\text{kg}}{1000 \times 100}$$

Ration size is also estimated by various methods using the feeding charts, feed equations, growth prediction and check tray etc. Feeding rates for seabass of 1-2 g is 20%, 2 -20g is 15-7%; 21-55 g is 6-4%, 56-180 g is 4-2% and when body weight is more than 180 g feeding rate is 2% of biomass. For assessing the average body weight, sampling needs to be done on regular basis i.e., weekly or fortnightly to recalculate the amount of feed to be given. Use of sensor based demand feeder may help for precise estimation of ration size which may be helpful in large scale farming.

Feeding frequency and time of feeding:

Feeding frequency is very important to increase feed utilization efficiency and to reduce the feed conversion ratio and to ensure maximum dressing percentage of cultured organism. Generally young fish are fed more often and the frequency of feeding decreases as the fish grow. The total feed required in a day should not be fed at a time. Frequent feeding of small portion of ration help in better utilization of the feed and thereby lead to efficient FCR. There must also be a mechanism in each case to monitor the feed consumption and offering of next dose of feed should be regulated on basis of consumption from the previous feed offered. In fish, 90% of offered feed should be eaten within 15-30 minutes of feeding time.

Feeding methods:

Feeding method is one of the important aspects for cost effective production of high quality fish. Depending on different factors such as labour costs, scale of farming, species under farming, type of system *i.e.* for hatchery or grow out systems, fish can be fed through hand feeding or mechanized feeding. Generally farmers feed their fish by directly broadcasting the feed in pond. Broadcasting or hand feeding is the most common form of feeding in the semi-intensive culture practices of the developing world. It is also used in intensive culture practices to varying extent. Feed bag with few small hole suspended at different places in ponds is also common method of feeding for fish. For improving feed utilization efficiency floating feed can be given in net enclosure and sinking pellet may be given in feed tray. Often farmers use a combination of feeding methods such as hand feeding to mechanized feeding. In mechanical feeding system, demand feeder is used in which fish approaches to the feeder for its feed requirements when they feel hungry. It was observed that fish quickly learn how to obtain feed. The growth of fish is good with best FCR and minimum wastage of feed in self-demand feeding system. This method works best with finfish farming. A reliable and least- cost feeding system should ensure the effective distribution and spread of adequate feeds in aquaculture ponds.

Rope bag feeding method

Feeding in net enclosure

Feeding management in shrimp culture system:

Proper feed management is essential for successful and profitable shrimp farming. Shrimp find their feed mainly by chemosensory mechanism rather than vision. Due to benthic feeding behaviour, sinking pellet feed should be offered to shrimp. Following points should be strictly followed while feeding the shrimp for maintaining good pond hygiene and to reduce wastage of feed and to avoid accumulation in pond bottom.

1) Proper feeding guidelines should be followed to fix ration size for shrimp culture pond
2) High quality feed should be used
3) Daily ration should be offered in 4/5 meals
4) Feed intake should be checked through check trays (6 nosperha)
5) Feed should be reduced up to 50% during major moulting
6) Feeding should be avoided during heavy rain
7) Feed of proper pellet size should be offered

Appetite of shrimp will vary due to the environmental conditions *i.e.*, water quality, water temperature, sunny/overcast days and physiological conditions such as disease and moulting. Feed should never be given in excess as uneaten feed pollutes the water. As shrimps are the nocturnal feeder, larger doses may be offered in the evening and during night. Unlike other shrimps, white leg shrimp (*Penaeus vannamei*) are more active during day time and hence major share of the ration is offered during day time. Generally during new moon and full moon moulting of shrimp takes place and they become physiologically less active and reduce the feed intake. Quantity of feed offered should be reduced at the extent of 30-50% during that period. Regular observations and experience helps in mastering the management of feeding in a culture farm.

Ration size, feeding frequency and time of feeding:

Generally the method of calculating the daily ration is based on the body weight of shrimp (Table 4 & 6). Blind feeding is generally practiced during first fifty days of culture (Table 3 & 6). Daily ration is divided and offered 2 to 5 times a day (Table 5 & 7) depending on stages of culture. The feeding activity and quantity of feed consumed may be checked by keeping feed in check trays (size: 80 cm×80 cm) @ 6 nos.per ha in different places in pond. After one month of stocking, consumption of feed should be checked by using check trays.Besides the ration size, the optimal feed particle size also affects the feed intake and growth of shrimp. Feed should be broadcasted evenly in a periphery of about 2 meters from dyke in all sides of the pond.

Table 3. *Ration size for first fifty days of tiger shrimp farming*

Age (Days)	Feed increment / day (g)	No. of meals / day	Feed (Kg) per day per lakh PL_{20}
1	-	2	2.0
2-10	400	2	2.4-5.6
11-30	600	3	6.2-17.6
31-50	500	4	18.1-27.6

Table 4. *Ration size after 50 days of culture in tiger shrimp based on check tray performance*

Days of culture	Expected ABW (g)	% of biomass as feed	Feed % in Check tray	No. of meals per day
51-55	6-7	5.0-4.8	2.0	4
56-60	7-8	4.8-4.6	2.2	4
61-65	8-9	4.6-4.4	2.2	4
66-70	9-10	4.4-4.2	2.4	4
71-77	10-12	4.2-4.0	2.6	4
78-83	12-14	4.0-3.7	2.7	4
84-90	14-16	3.7-3.5	2.8	4
91-97	16-18	3.5-3.2	2.9	4
98-104	18-21	3.2-2.9	3.0	4
105-110	21-24	2.9-2.7	3.2	4
111-117	24-27	2.7-2.5	3.3	5
118-124	27-30	2.5-2.2	3.5	5
125-131	30-33	2.2-2.0	3.6	5
131-133	33-36	2.0-1.8	3.7	5

Table 5. *Feeding Schedule for tiger shrimp*

Feed type	Shrimp weight (g)	Time of feeding				
		6.00 AM	11.00 AM	6.00 PM	10.00 PM	2.00AM
Starter	Up to 4.0	30 %	-	35%	35 %	-
Grower	4 – 25	25 %	15 %	30 %	30 %	-
Finisher	> 25	25 %	15 %	20 %	25%	15%

Table 6. *Ration size for Penaeus vannamei*

Age in days	Feed increment/ day	Feed(kg)per dayper lakh PL_{15}
1	-	2.0
2-10	400	2.4-5.6
11-20	500	6.1-10.1
21-30	600	10.7-15.5
31-50	700	16.2-28.8

Age in days	**Feed increment/ day**	**Feed(kg)per dayper lakh PL_{15}**
Body wt.(after 50 days)	% of biomass	Feed % in Check tray
5-10	5.5-4.5	2.4-2.8
10-15	4.5-4.0	2.8-3.0
15-20	4.0-3.5	3.0-3.3
20-25	3.0-2.5	3.3-3.6
25-30	2.5-2.0	3.6-4.1

Table 7. *Feeding schedule in Penaeusvannamei farming*

	Percentage of daily ration in meals				
	6 AM	9 AM	12 PM	3PM	6 PM
First month	40	-	-	60	-
Second month	40	-	-	30	30
Third month	20	20	-	30	30
Fourth and fifth months	15	15	10	25	35

Check tray monitoring :

Quantity of feed to be kept in check tray depend upon pond size and average body weight of shrimp and can be determined using the following formula

$$\text{Quantity of feed (g)} = \frac{1600}{\text{Area of pond}} \times \frac{\text{Feed \% in check tray}}{100} \times \text{Quantity of feed in a meal (g) in each check tray}$$

For example, feed quantity in each check tray for a meal (3 kg) for shrimp in 1500 sq m pond sizes would be:

$$\text{Feed quantity in each check tray} = \frac{1600}{1500} \times \frac{2.8}{100} \times 3000 = 89.6 \text{ g}$$

The check trays should be observed after 2 hr of feeding .Depending on the quantity of feed consumed in the check tray, the next dose should be increased or decreased. Feed is to be reduced by 50% during moulting, shortage of dissolved oxygen and stressed condition due to heavy rain, high temperature, unfavourable pond bottom and water quality.

Success of feed management depends on the farmer's experience and observation on the feeding behaviour and feed intake of shrimp. Following a strict feed management, tiger shrimp can attain average weight of 30-35 g with survival up to 70-80% in culture duration of 120 days, whereas exotic white leg shrimp could achieve 20-25 g with a survival of 80-90% in 100 days culture period. Progressive farmers may form co-operative society and can have small scale feed mill to prepare shrimp feed using locally available feed ingredients for tiger shrimp/ vannamei shrimp/Indian white shrimp culture and may get a good economic return.

Disease management in brackishwater aquaculture

In spite of being one of the fastest growing food sectors, brackishwater aquaculture very often is being affected with different diseases, which are major hindrance for the growth of this sector. White spot disease (WSD) in shrimp alone caused cumulative economic loss as high as ₹3,000 crores during the period 1995-2005. The predisposing causes of diseases in brackishwater aquaculture systems are lack of proper awareness of disease management among the farmers, inadequate biosecurity measures and lack of monitoring of soil and water quality parameters. In case of traditional brackishwater aquaculture (*e.g.*, bheries of West Bengal); unavailability of disease-free shrimp post-larvae, use poor quality feed (*e.g.* trash fish, leather meal, etc.), poor technical knowledge among the farmers, inadequate financial support are the contributory factors to the occurrence of diseases. Adoption of better management practices (BMPs) and proper education among the farmers on disease management are of topmost importance for prevention of disease problems in shrimp farms.

Important diseases of brackishwater aquaculture systems:

For cultured shrimp:

- White spot disease (WSD)
- Enterocytozoon hepatopenaei (EHP) infection
- Early mortality syndrome (EMS) or Acute Hepatopancreatic Necrotic Disease (AHPND)
- White Faeces Syndrome (WFS)
- Yellow Head disease (YHD)
- Taura Syndrome (TS)
- Infectious myonecrosis (IMN)
- Vibriosis
- Loose Shell Syndrome (LSS)

For cultured brackishwater finfish:

- Epizootic ulcerative syndrome (EUS)
- Viral nerval necrosis (VNN)
- Vibriosis

For cultured crab:

- Crab reoviral infection
- Shell fouling disease

White spot disease (WSD) is caused by White spot syndrome virus (WSSV) is the most important diseases of cultured shrimp including *Penaeus monodon* and *P. vannamei*. In case of *P. monodon*, this disease is the single major cause of mortality in cultured shrimp. The disease is characterized by crowding to pond margin, lethargy, loss of appetite and red to pink discolouration of the body. The affected shrimps showed the presence of white circular spots on the exoskeleton, especially on the carapace portion. WSSV can infect all penaeid shrimp and can be transmitted by both horizontal and vertical route. The stressful environmental conditions like sudden change of salinity & pH, temperature, low dissolved oxygen, etc. are predisposing factor of this disease. Very high mortality is observed in cultured shrimp, especially in *P. monodon*. Horizontal transmission of this disease from environment mostly takes place in intensive and semi-intensive culture systems whereas, vertical transmission is common in traditional aquaculture systems, where the use of disease-free post larvae is not in practice. Different species of rotifers, crabs, crayfish, polychaetes, artemia, birds, algae, etc. may act as carrier of the disease. The disease can be diagnosed by observation of gross symptoms and screening of affected shrimp by PCR. The use of Specific Pathogen Free (SPF) shrimp post-larvae (PCR-tested WSSV-free post-larvae in case of *P. monodon*), maintenance of soil and water quality parameters and adherence to proper biosecurity measures are the most important features for control of this disease.

Microsporidiosis caused by *Enterocytozoon hepatopenaei* (EHP) is the most important emerging disease in case of cultured shrimp in India, especially *P. vannamei*. Unlike WSD, mortality rate is generally very low in this infection. However, the shrimp farmers suffer a tremendous economic loss in case of EHP infection due to retardation of growth. Very often, shrimps with EHP infection exhibit White faeces syndrome (WFS). The microsporidia generate spores, which are very resistant to adverse environmental condition. Spores remains alive even after harvest for long period and can even resist all conventional pond preparation techniques including drying and bleaching. The residual spores present in the pond can infect the subsequent cultures leading to heavy long-term economic losses to the farmers. However, the EHP spores are sensitive to high alkaline condition. Before subsequent cultures after EHP infection, the pond bottom may be treated with very high dose of quick lime (3-6 Tons per Hectare) to destroy the EHP spores.

Early mortality syndrome (EMS) or Acute Hepatopancreatic Necrotic Disease (AHPND) is characterized by heavy mortality of shrimp at early stages (Within 35 DOC of stocking) with shunkenhepatopancreas. This disease is caused by some strains of *Vibrio parahaemolyticus* bearing specific plasmid. Although there is no confirmed report of this disease in India, the disease has been reported in most of the shrimp-growing countries of Asia including Bangladesh, the immediate neighbouring country of India. Thus, the farmers, scientists and aquatic health specialists should be very vigilant for this disease. White faeces syndrome (WFS) is also one of the most commonly occurring diseases of shrimp culture systems throughout the World including India. The important causes of the WFS are infection with EHP and infection with different harmful bacterial species due to poor culture environment. Poor feed management is an important contributory factor to this disease. Infectious myonecrosis (IMN), which is also a viral disease, has also recently emerged in India. The disease is characterized by necrosis of the abdominal muscle of the shrimp with whitish and reddish discolouration and opaque appearance. Vibriosis in shrimp is generally caused by different species of *Vibrio*, which are considered as normal habitant of Brackishwater aquaculture system. But some species of *Vibrio*, especially the luminescent species act as opportunistic pathogens and affect cultured shrimp especially in case of stress due to poor culture condition. Yellow head disease and Taura syndrome are two important viral diseases of cultured shrimp. Both the diseases are not prevalent in India. However proper vigilance and surveillance are required for both the disease as both the diseases are prevalent in several shrimp-growing countries.

As per diseases of brackishwater finfishes are concerned, Viral nerval necrosis (VNN) caused by beta-nodavirus is the most important diseases with high degree of mortality, especially in juvenile stages of Asian seabass. The disease also affects other brackishwater fishes including *Mugil cephalus*, *Chanos chanos* (Milk fish), *Epinephelus tauvina*, *Amblygaster clupeoides*, *Mystus gulio*, *Leiognathus splendens*, etc. The disease is transmitted by contaminated water, introduction of infected juvenile fish and through different wild fish species, which often act as carrier. The vertical transmission can also take place from infected spawners. The causal organism beta-nodavirus attackes Central nervous system and causes vaculation of Central nervous system. Most important symptoms are anorexia, dark discolouration of the body, necrosis in different parts of the body and characteristic swimming behavior known ‘spiral swimming’. Epizootic ulcerative syndrome (EUS) caused by *Aphanomyces invadans* is the most important diseases of freshwater aquaculture system. However, this disease also infects some Brackishwater fishes including Asian seabass (*Lates calcarifer*), grey mullet (*Mugil cephalus*), nunatengra (*Mystus gulio*), etc, especially when water salinity becomes low. The disease is more prevalent during onset of winter and after heavy rainfall. Other important diseases of freshwater fishes including fin rot, tail rot, dropsy, columnaris disease, etc. sometimes affects brackishwater cultured finfishes. However, both morbidity and mortality is lower in case of brackishwater finfish than freshwater finfish.

Crab reovirus infection is most important disease of crab with high mortality. This virus attacks the hepatopancreas and gill of cultured mud crab (*Scylla serrata*). However, this disease is not prevalent in India. In India, the important crab disease is ‘Shell fouling disease’, in which fouling of crab shell takes place by mixed infection with fungus, algae and filamentous bacteria. The condition is more aggravated by secondary infection with fouling bacteria. The deterioration of pond bottom is the main cause of this disease. Treatment of pond bottom with lime and potassium permanganate mixed with sand reduces the severity of the disease.

Measures to be followed at field level for control of brackishwater aquaculture diseases

For successful brackishwater aquaculture, Better Management Practices (BMPs) as per guidelines of Coastal Aquaculture Authority (CAA) should be followed properly. The guidelines are available at CAA website (www.caa.gov.in). The followings are some important aspects of successful management of Brackishwater aquaculture:

- Proper pond preparation: For successful brackishwater aquaculture, the proper pond preparation is the first step. Pond should be dried properly for 3 weeks and black soil should be excavated. The pond should be limed properly with 300-500 kg lime per hectare. The requirement of lime will be more, when the pH of the soil is below 7.0. Please refer to the CIBA guidelines (http://www.ciba.res.in/Books/ciba0295.pdf) for estimation of quantities of lime required.
- Biosecurity measures including installation of crab fencing, bird fencing, etc. should be followed properly.
- Disinfection of pond water should be done by application of good quality bleaching (450-690 kg per Hectare) at least 14 days before stocking.
- Shrimp post-larvae for stocking should always be procured from reputed hatcheries. The list of CAA approved hatcheries for *P. vannamei* are available at CAA website. The shrimp post-larvae should be free from WSSV and EHP and stocking should be done with at least PL-10 stages of post-larvae.
- Avoid over-stocking. As per CAA guidelines, the maximum permissible stocking densities for *P. monodon* and *P. vannamei* are 30 and 60 per square meter, respectively.
- After harvest of shrimp, treat the water with bleaching and discharge at least 7 days after treatment with bleaching.
- Cultured brackishwater finfish and shrimp should be monitored for any abnormal symptoms and behavior, which can immediately should be brought to the notice of aquaculture health specialists.
- Cultured water should be monitored regularly for any visual abnormality with regards to colour and transparency. Water quality parameters should be tested periodically and proper remedial measures should be taken (if required) with consultation with aquaculture health specialists.
- Indiscriminate use of aquaculture medicine without consultation with aquaculture health specialists should be strictly avoided. Use of almost all antibiotics is banned as per guidelines of different seafood importing countries.
- Optimum feeding is one of the most important aspects of disease management, especially in case *P. vannamei*. Over-feeding causes wastage of feed leading to deterioration of culture environment and render the cultured aquatic species susceptible to disease.
- Maintain proper water depth, which is around 125 and 150 cm for *P. monodon* and *P. vannamei*, respectively.
- It is advisable to designate one pond as reservoir pond, in which bleached water can be stored for possible urgent requirement for culture.
- Diseased and dead shrimps should be disposed properly to prevent spread of contagious diseases. Those should be buried following application of bleaching and lime preferably away from the pond. Provide separate nets and other equipments for each of the ponds in the farm.
- The workers of the farm should be monitored for good health status and proper sanitary measures.

Nutritional Management to Increase the Productivity of Dairy Animals in the Coastal Region

MONOJ KUMAR GHOSH*, VIPIN, M. KARUNAKARAN and AJOY MANDAL

ICAR-National Dairy Research Institute, Eastern Regional Station, Kalyani-741 235, India

**Corresponding author:* E-mail:monojghsh@rediffmail.com

Coastal areas are generally described as the interface or transition zones between land and sea. India has over 7500 km of long coastline. The majority of people living in the coastal region are dependent on the cultivation of crops, fish and livestock for their livelihood. In addition to providing food and income security, livestock also provides social and cultural values to the farming community. The production potential of livestock depends largely on the management practices under which they are grown, and these practices vary greatly across different regions due to several factors. Knowledge of livestock management practiced by farmers in a region is critical for identifying the strengths and weaknesses of rearing systems and for formulating successful intervention policies (Gupta *et al.*, 2008). In animal husbandry, one of the most important tasks is feeding. It is generally agreed that animal would fail to prove their complete genetic capacity for greater production when fed at low levels. Therefore, proper nutritional management is essential to optimize livestock production in the coastal area.

Constraint of livestock farming in the coastal region

With small variations, the climate of most coastal sub-regions in India comes under hot and humid or sub-humid conditions, except the semi-arid North Gujarat coast. The soil is calcareous and alkaline, mildly to moderately salty. In saline soils, nutrient deficiencies of nitrogen, phosphorus and micronutrients like copper and zinc etc. are very common. As a consequence, the production of fodder crops in the coastal area has decreased. Due to heavy rains for several months, green fodder cultivation is also difficult. The scarcity of livestock feed in both quality and quantity, especially in the dry season, is a major problem for livestock productivity in coastal areas.

Reasons for low animal productivity in the Coastal region

The large numbers of farmers in the coastal regions are smallholders. The largest populations of dairy animals in the coastal region are indigenous cows, followed by crossbreds and buffaloes. The explanation for this trend may be that the desi cow maintenance needs less care as they are more immune to disease and survive on low-quality feeds and fodder (Manabendra and Pipyaman, 2016). The main ingredient used in the coastal region is paddy straw as dry fodder. Around 44 per cent of farmers feeding compound cattle feed to their milking animals as a concentrate, based on milk production, primarily after milking. Just 38 per cent of farmers have provided their dairy animals with a mineral supplement and 88.67 per cent of farmers did not supply their dairy animals with extra salt. The majority of farmers (82 per cent) supplied their animals with non-leguminous green fodder, while just 32 per cent of farmers supplied their animals with non-leguminous + leguminous green fodder in the coastal area of Gujarat (Sabapara, 2016). Owing to the lack of green fodder and lack of awareness about silage making in study areas, a few numbers of farmers practiced silage making. Therefore, the average first calving age, the mean calving interval and the postpartum estrus interval are relatively long with a higher problem of silent heat in the coastal area. There is a scarcity of pasture land and fodder crops for livestock production because of increased salinity.

Programme for ration balancing

Scientific information about feeding is not accessible to unorganized small farmers in the coastal area, resulting in imbalanced and insufficient animal feeding. Programmes for ration balancing can play a vital role in overcoming it. Ration balancing programme can be formulated with the available feed resources in the coastal region at the farmer's level. It consists of various software packages which, based on the physiological and production status of the animals, decide the nutrient requirements of the animal and formulate the least-cost ration specific to that animal.

The use of the ration balancing programme has the advantages such as the effective use of available feed resources, the potential reduction of daily feeding costs, and the improvement of animal reproductive and productive life.

Enrichment of crop residues and densification

There is a net scarcity of different feed types in the coastal area, such as concentrate, dry fodder and green fodder. The available feedstuffs already have low nitrogen, high fibre content. Crop residues provide a good alternative in such a case. However, these fibrous residues are of low nutritional value but can function as an important source of livestock feeding, particularly in the coastal area. Unfortunately, they are not equally dispersed across the country, so a farmer needs to bear significant costs as a result of transporting wide distances of low bulk density residues. In such a scenario, the enrichment and densification of crop residues is therefore a crucial choice. Such types of newer techniques are as follows:

I. Straw based pellets

II. Straw based blocks

III. Straw based briquettes

These methods increase the bulk density, thereby lowering shipping costs and handling costs, providing better palatability and helping to formulate a healthy ration for animals in the coastal area.

Usage of urea molasses mineral block (UMMB)

UMMB allows the use of urea to provide the ruminant animals with proteins. The addition of molasses ensures the optimal supply of energy to the rumen microbe so that microbial proteins can be synthesized by using urea-generated NH_3 and therefore avoids the potential for NH_3 toxicity to the animal. The inclusion of minerals and vitamins in the same block has the added advantage of supplying the animal with the maximum supply of these nutrients. This technique, together with dry fodder, can meet the maintenance requirements of animals, especially during the coastal region's natural calamities. It enhances the consumption of crop residues, straws, kadbies, etc., resulting in lower waste. It also increases the digestive efficiency of dry fodder, which helps to increase the quality of milk and provides greater milk fat content. Although it has many advantages, block shape loss, particularly during hot summer days with high humidity in the coastal region, toxicity chances impose difficulty in use.

Area-specific mineral mixtures supplementation

The soil in coastal regions is deficient in various minerals because the coastal soil has different pH, content and texture. Minerals are essential nutrients which play an important role in the animal's overall health and production efficiency. While mineral content is adequate in some feeds, they have poor availability. Therefore, animals do not receive an adequate supply of certain important macro and micro minerals that lead to their deficiency, which can lead to certain systemic, physiological or immunological disorders that affect development, production and reproductive health. In various coastal areas, the mineral profile of soil and plants and of animals varies. Mineral deficiency is, therefore, a region-specific issue and a feeding strategy should seek to complement mineral mixtures explicitly intended for this area. This can be achieved by providing the animal's diet with ASMM. The provision of ASMM provides a better growth rate for young calves, which also improves the efficiency of the use of feed and increases the animal's milk production. It also decreases the inter-calving cycle, thus increasing the productive life of animals and increasing resistance to infectious diseases. Thus overall it is a cost-effective method for higher production & better health of the animal in the coastal region.

Bypass nutrient technology

There is a general shortage of good nutritional feed and fodder in the coastal area, so that the animals, especially dairy animals, cannot meet their requirement that ultimately reduces the production and reproductive output of the animals. Nutrient bypass technology is a good option for farmers in coastal regions to tackle this problem. Bypass nutrient means that the nutrient fraction that gets less fermented in rumen and becomes available for subsequent digestion and absorption at the lower part of the GI (gastro-intestinal) tract. The whole purpose behind this technology is to prevent nutrient losses and make the digestion process more and more effective. Thus, by using the chemical treatment of these feeds, the quality of the animal's usage can be greatly modified. In the coastal area, where quality feed supplies are available in limited quantities and farmers have to bear a significant price for their supply, this technique has high practical implementation potential.

Bypass protein supplements

Typically, protein is the first limiting nutrient for low-quality forages eaten by cattle and buffalo. An inevitable result of digestion and in certain conditions is the microbial fermentation of soluble protein in the rumen; it is a costly approach since high-quality proteins are broken down into ammonia, surplus transformed into urea in the liver and excreted via urine. In the rumen, bypass proteins are less fermented and transfer to the lower intestine undegraded and digested and absorbed there. Thus, the RDP: UDP ratio (Rumen Degradable Protein (**RDP**)/Undegraded Dietary Protein (**UDP**)) can be effectively sustained by supplementing it. These slowly degradable proteins act as a source to provide a steady nutrient supply to the rumen microbe instead of a quick burst of easily soluble proteins. Protein supplement bypass ensures greater availability of amino acids per feed unit, resulting in better use of protein meals with greater degradability of rumen protein. It also allows for the judicious use of minimal amino acids such as lysine and methionine by increasing their supply to the small intestine. This leads to an increased growth rate, protein per cent (0.1-0.3 per cent) & milk SNF (solids not fat) content, and thus total milk production (0.8-1.2 litres/day).

Bypass fat supplements

Bypass fat is the fraction of dietary fat in the lower digestive tract, which avoids lipolysis and biohydrogenation in the rumen by rumen microorganisms, but gets digested. Bypass fat supplementation has tremendous economic significance as milk values are measured on fat percentage and it helps to improve that. It is made up of long-chain saturated fatty acids that are partly released in the rumen but mostly travel into the small intestine where 95 per cent of them are digested. The fatty acids travel from the blood to the udder, where they can be directly absorbed into the milk fat. This raises the production of milk and milk fat. Calcium salts of long-chain fatty acids (Ca-LCFA) are most commonly used by all types of bypass fat because it is comparatively less degradable in the rumen and has the highest intestinal digestibility and also serves as an additional source of calcium. To satisfy their nutritional requirements within a small DMI (dry matter intake), it is very important to increase the energy density of the ration of highly producing dairy animals. In the ration of this we will prevent the decrease in fibre intake and acidosis, milk fat depression like diseases, there is no need to incorporate concentrate at a higher level. It also minimizes the loss of body weight after calving, so better reproductive success is possible by early returning to the positive post-calving energy balance. Bypass fat supplementation has no detrimental impact on rumen fermentation, feed intake and nutrient digestibility when the ration includes 4-6% fat in the case of high-producing animals.

Bypass carbohydrates supplements

It is primarily intended for the feeding of highly productive animals. To minimize the excess output of lactic acid in the rumen, these animals are fed with bypass starch, which can otherwise hinder fibre digestion due to the acidic condition of the rumen, so the starch that bypasses ruminal degradation is digested in the small intestine and absorbed as glucose, which is more energy-efficient compared to lactic/propionic acid absorbed from the rumen wall. The fermentation of maize starch in the rumen is very minimal and is therefore known as a natural source of carbohydrate bypass. Urea therapies for formaldehyde treatment are well-known strategies to prevent starch ruminal hydrolysis and make it bypass carbohydrate. Formaldehyde treatment, urea treatments are well-known techniques to resist ruminal hydrolysis of starch and make it bypass carbohydrates.

Feed additives

Feed additives can be used to increase the productivity of the animals in the coastal area. We have been using various feed additives such as vitamins, minerals, enzymes, hormones since long ago, which have shown relatively good results. Newer additives such as probiotics, antibiotics, toxin binders, etc. With the growth of nutritional science, these patterns will continue to shift. While many of the feed additives are extremely costly, the animal output is still attracting industry to use them. To enable the animal to have improved production efficiency, these additives function on another aspect of digestion and metabolism. When using these, we need to have a selective approach to support economics for more cost-effective development. This class is very broad and there is an individual debate beyond the reach of this paper.

Compound cattle feed

Compound feed in the coastal area may play a crucial role in the nutrition of producing animals. The compound feed consists of various feed resources such as cakes, grains, brans, chunnies, etc., so the nutritional demand of animals can be met more effectively and economically when fed along with the basal diet. This form of feed ensures an adequate supply of different nutrients at levels sufficient to satisfy the demand of the animals so that their output capacity can be completely exploited. A compound feed can provide animals with a level of 16-20 per cent of CP (crude protein), but it is difficult to check rations at the doorstep of farmers for such parameters. Thus an easy formula (given in Table below) is developed for this i.e. formula 33:33:33:1- Protein Source: Cereals: Agricultural Byproducts: Mineral Mixture. A good quality compound feed can be prepared easily by remembering this. A slight modification like the replacement of agricultural byproducts by salt and/or lime as a source of Ca @1% individually whenever necessary can give an ideal compound feed.

Fraction	Source	Examples
33%	Protein Source	Cake, meal
33%	Cereals	Maize, Jowar, Barley, Oat
33%	Agricultural Byproducts	Bran, chuni, husk
1%	Mineral Mixture	-

The standardized distribution of micronutrients is highly desirable for the supply of balanced nutrients during the preparation of compound feed, for which premix formulation is of utmost importance and a practical solution for farmers preparing the homemade compound feed.

Use of unconventional feed as feed for animals

The marine algae (seaweed) have been used since ancient times for animal feed in coastal areas. Seaweeds are combined with animal feed as they can harm livestock when eaten alone. Seaweed is also very rich in useful metabolites (pigments, carotenoids, phlorotannins, polyunsaturated fatty acids, agar, alginate and carrageenan) and minerals (iodine, zinc, sodium, calcium, manganese, iron, selenium) and is known to be a natural source of additives that can supplement the use of antibiotics in different species. Seaweeds colonize marine environments and are used by coastal communities in particular. For livestock, seaweed biomass is an important substitute ingredient. In general, macro-algae exhibit significant protein, mineral, lipid and fibre variations. Because of their ability to absorb inorganic substances from the atmosphere, the high mineral content of marine algae contains a limited amount of lipids, primarily polyunsaturated fatty acids (PUFAs), while they are abundant in polysaccharides. There is just a small amount of lipids in seaweed (1-5 per cent), but most of those are PUFAs. More PUFAs 20:5 n-3 (EPA) (Eicosapentaenoic acid) and 20:4 n-5 (arachidonic acid) are found mostly in brown and red seaweed than in green algae (Mišurcová *et al.*, 2011). The composition of seaweed is highly variable and depends on the organisms, collection period, habitat and environmental factors, such as water, temperature, light intensity and concentration of nutrients in the water. Sugar beet (Beta vulgaris L.) is a promising summer crop of high yield that can be grown well in the southern Gujarat coastal region. It has some advantages over conventional fodder crops that it can tolerate up to 5 ECe of soil salinity. This complete yield, above and below the ground, can be used directly for animal feeding. The sugar beet top can also be used in the processing of silage. Bamboo cultivation is a low-input system with great rewards, providing a variety of benefits as building materials, to prevent soil erosion and, potentially, providing feed for livestock. Bamboo leaves can provide an important component of diets and enable the maintenance of the animal performance through the year, especially during seasons of fodder shortage.

Improving the supply and conservation of fodder

The scarcity of fodder can be resolved in the coastal area by using traditional/local feed/fodder crops with a proper intercropping method. It is possible to integrate the annual and perennial fodder crops/trees into the crop calendar. With adequate technology backup, the necessary storage mechanism for the fodder and feeds can be adopted. Recent feasibility studies have shown some hope that the requirement for feed and fodder via maize cultivation would be partially fulfilled. During the rainy season in the uplands and as an intercrop in hilly terrain along with young plantation crops, the best technique is to grow maize for fodder. The corn stover is straw-like and can be used as fodder. There is also green fodder available, while silage can be used with the surplus green stover. In the coastal area, farmers depend on forage to feed livestock. Forage production is rain-fed, so feed during the dry season is scarce and of low quality. Milch cattle experience extreme nutritional stresses as a result of inadequate feeding, resulting in reduced productivity; most significantly, low milk production. Fodder conservation is a choice during the dry season to provide high-quality feed. During the rainy season, natural pasture is readily available, so the surplus can easily be stored. Hay is also made from a mixture of natural pastures and usable fodder aside from natural pastures. Lack of management skills and expertise, insufficient resources to preserve and the high cost of labour and materials used for conservation are the key constraints on forage conservation in the coastal area.

Conclusions

Livestock farming plays a huge role in the livelihood of the coastal region and vital role in nutritional sufficiency for feeding of coastal communities. Nutrition plays the most important role in realizing the production potential of animals and thus it has been recommended time to time to spend around 70% of total cost alone on feeding. But the unavailability of sufficiently good quality feed contributes the major factor towards limiting productivity in the coastal region. Ration balancing programme and balanced feeding ensure an optimum supply of required nutrients to the animal to enhance productivity. Densification of crop residue, supplementation of UMMB (Urea molasses mineral block) is the strategies for reducing daily feed cost by using locally available cheaper resources and thus enhances the cost-effectiveness of animal production. Inclusion of different nutrients like proteins, fat and carbohydrates in rumen bypass form is minimizing the nutrient losses in fermentation thus making their use more judicious resulting in more efficient production. Supplementation of the ration with ASMM (area specific mineral mixture) ensures supply of required minerals in optimum quantity avoiding both deficiencies as well as toxicity. Inclusion of different feed additives is giving animals required boost for enhancing production. These different techniques have their benefits and limitation however one can apply them individually or in combination to optimize the animal production and make the enterprise a more profitable one. Unfortunately, unawareness about some of these practices has laid to modest improvement in livestock productivity in the coastal region.

Recommendations

As a follow-up to the improvement of dairy animals in the coastal region, the following recommendations are proposed.

1. Dissemination of fodder conservation technology in a simple and easy to practice format to be carried out among the farmers and hands on training to be provided
2. Strategies for improving the supply of hay and silage materials should be embraced. The cost of silage production should be reduced by using low-cost inputs
3. Further research on the economic feasibility of dairy farming in the coastal area needs to be conducted.
4. Development of more numbers of dairy plants in the coastal area for the development dairy cooperatives, to provide veterinary health and production support for the benefits of dairy farmers.

BIBLIOGRAPHY

Datta, K.K., Kumari, B. and Singh, P. (2014). Value chain analysis of feed and fodder in India. In: National Symposium on "Climate Resilient Forage Production and its Utilization" held at BCKV, Kalyani, West Bengal, India, November 13-14, 2014, pp. 84-88.

Datta, T.K., Mondal, A., Chatterjee, A. and Ghosh, M.K. (2014). Sustainable animal production in eastern India: Impact of improved feeding system. In: National Symposium on "Climate Resilient Forage Production and its Utilization" held at BCKV, Kalyani, West Bengal, India, November 13-14, 2014, pp. 95-104.

Garg, M. R., Bhanderi, B. M. and Sherasia, P. L. (2007). ASMM and vitamins in the ration of dairy animals for improved productivity and reproductive efficiency. *Indian Dairyman* **59(8):** 21-27.

Garg, M. R. and Bhanderi, B. M. (2011). Enhancing Fodder Availability in Rain fed Regions. In Livestock Productivity Enhancement with Available Feed Resources. Excel India Publishers, New Delhi, Page No. 11-21.

Kundu, S. S., Kewalramani, N., Mani, V. and Datt, C. (2011). Potential Newer Technologies for High Yielders Maintained on Commercial Farms. In Livestock Productivity Enhancement with Available Feed Resources. Excel India Publishers, New Delhi, Page No. 22-31.

Misra, A.K. (2014). Crop residue for feeding of livestock in India: Status, nutritional variability, quality improvement and issues. In: National Symposium on "Climate Resilient Forage Production and its Utilization" held at BCKV, Kalyani, West Bengal, India, November 13-14, 2014, pp. 89-94.

Mišurcová, L.; Mach ˚u, L.; Orsavová, J. (2011). Seaweed minerals as nutraceuticals. In Advances in Food and Nutrition Research; Elsevier: Amsterdam, The Netherlands, pp. 371–390.

Ray, M. and Sengupta, D. (2016). Role of livestock in integrated farming in coastal saline zone of West Bengal. *International Journal of Farm Sciences* **6(2):** 191-201.

Sabapara, G.P. (2016). Feeding management practices of dairy animals in coastal areas of Navsari district of India. *Livestock Research International* **4(2):** 88-93.

Tiago, M., Inácio, A., Tiago, C., Ministro, M., Cotas, J., Pereira, L., and Bahcevandziev, K. (2020). Seaweed Potential in the Animal Feed: A Review. *Journal of Marine Science and Engineering* **8:** 559; doi:10.3390/jmse8080559.

Tomlinson, D. J., Socha, M.T. and DeFrain, J.M. (2007). Cow immunity boosted with trace minerals. Feed Tech Magazine. Vol. 11. No. 10.

Wistrand, A, (2003). "Shrimp farming in Bangladesh," in the Blues of a Revolution: The Damaging Impacts of Shrimp Farming, D. Torre and D. Barnhizer, Eds.

Application of Remote Sensing in the Estimation of Suspended Sediment Concentration: A Case Study of an Estuary in Eastern Coast of India

CHIRANJIVI JAYARAM*and NEETHU CHACKO

Regional Remote Sensing Centre – East, NRSC / ISRO, Kolkata West Bengal 700156, India

**Corresponding author:* E mail: jayaram_cv@nrsc.gov.in

The coastal regions are inhabited by 60% of the entire global population and more than 75% of the rivers discharging sediments into these regions. Also, the turbulence near the river mouths and estuaries impact the local (or shoreline) geomorphology owing to the varying sediment balance. Variations in the distribution of sediments in the estuaries impact the aquatic flora and fauna, navigation and also the sustainable development of the coastal zones. The study of suspended sediments is ecologically important as they are major carriers of various inorganic and organic substances that form the constituents of biogeochemical processes (Doerffer *et al.*, 1989). Suspended sediment gradient also leads to reduction in level of turbulent kinetic energy and eddy conductivity which is a very useful aspect in coastal ocean modelling (Adams *et al.*, 1981). Suspended sediments attenuate the light penetration in to the water column through absorption and scattering; thus, the sediment concentration is a key parameter for assessing water clarity and its overall quality. Therefore, spatio-temporal studies on the suspended sediments are crucial to understand the coastal processes in local and regional scale of a given region.

Analysis of case 2 water quality parameters using remote sensing approach in the visible to NIR band mainly involves estimation of total suspended matter (TSM) concentration, turbidity estimation, chlorophyll-a (chl-*a*) concentration, etc. Satellite remote sensing greatly expands the spatio-temporal coverage of the marine environment compared to in situ monitoring of the total suspended matter (TSM).Various studies have successfully mapped TSM in a wide range of coastal waters using the Advanced Very High Resolution Radiometer (AVHHR) (Stumpf, 1987), the Landsat Thematic Mapper (TM), the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) (Tassan, 1994) and the Moderate Resolution Imaging Spectroradiometer (MODIS) (Miller *et al.*, 2004). MODIS has advantage in ocean colour remote sensing due to twice daily coverage and high spatial resolution of 250 m (Chen *et al.*, 2015). TSM spectral signature data used in various studies suggests that wavelength range from 550 nm to 700 nm is proven to give better results in TSM retrieval for different concentration levels over different regions (Nechad *et al.*, 2010; Yang *et al.*, 2017).

The present study addresses the sediment dynamics of the Hooghly estuary using remote sensing observations. The Hooghly estuary (Fig. 1) is situated between 21.00°N and 22.50° N latitude and 87.00°E and 89.00°E longitude, is the western boundary of the largest delta in the world, formed by the distributaries of the rivers Ganges and Brahmaputra. It is the largest macro-tidal, delta front and monsoonal estuarine system that widens to a width of ~4 km to the south of Diamond Harbour and discharges into the Bay of Bengal (BoB). This estuary is well-mixed with a depth of ~6m and drains a catchment of around 6×10^4 km^2 with a semi-diurnal tidal system ranging from 5.2 m at spring and 1.8 m at neap (Sadhuram *et al.*, 2005). The dominant seasons in the study area could be classified in to three based on the monsoon system (Mukhopadhyay *et al.*, 2006): pre-monsoon (March – May), monsoon (June-September) and post – monsoon (October-December).

Satellite Data

In the present study, satellite observations of Landsat 8 are used to estimate and map the seasonal distribution of TSM concentration in the Hooghly estuary. Landsat 8 has 11 bands at different spatial resolutions (8 multi-spectral bands at 30 m, 1 panchromatic band at 15 m and 2 thermal bands at 100 m resolution) with a repeat period of 16 days.The Operational Land Imager (OLI) onboard Landsat 8 with higher signal to noise ratio, higher radiometric resolution (12-bit) and a spatial resolution of 30 m is suitable for resolving the near shore sediment concentration (Trinh *et al.*, 2017). Daily data of the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard Aqua

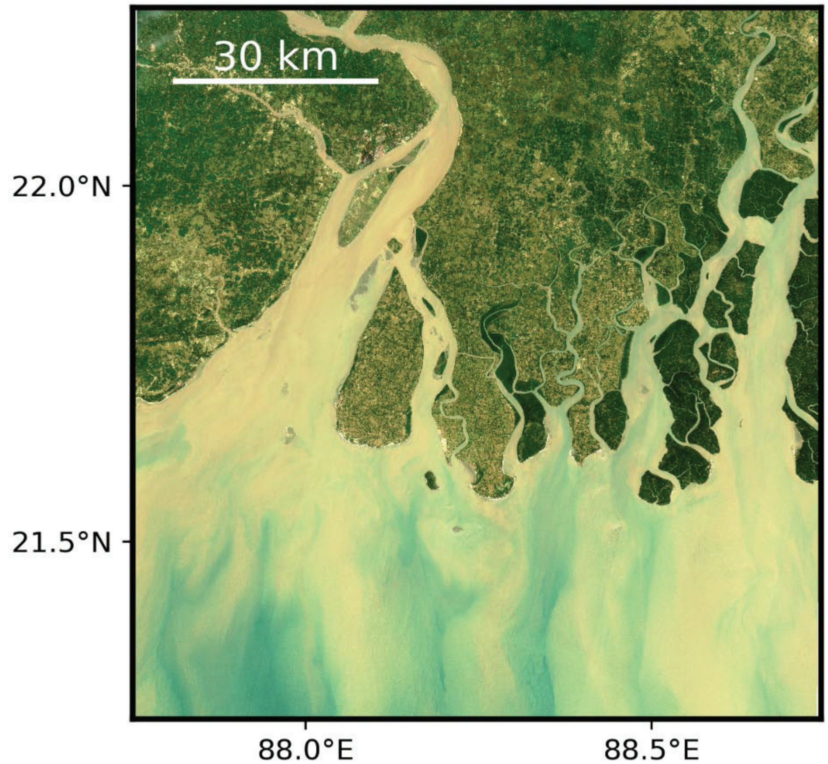

Fig. 1. Satellite image of the Hooghly estuary and the adjoining Sundarbans region

250 m surface reflectance is used to delineate the impact of tides on the sediment distribution in the study region. MODIS has 36 spectral bands with spatial resolution ranging from 250 m to 1000 m. MODIS data provides global coverage with twice a day temporal resolution. MODIS MYD09GQ surface reflectance product consists reflectance data for band1 and band2 with wavelength ranges from 620nm to 720nm and 841nm to 876nm respectively, L2G product is geo-referenced and corrected for atmospheric effects (Vermote *et al.*, 2002).

TSM is derived from the satellite datasets by using the generic single band algorithm developed by Nechad *et al.* (2010) the accuracy of which is ± 10 g m-3. In the present study water leaving reflectance in the Red band is used to obtain the TSM using the expression given below:

$$\text{TSM} = \frac{A\rho w}{1 - \frac{\rho w}{c}}$$

here, ρ_w is the water leaving reflectance (655 nm), A = 289.29 and C = 0.1686 are the coefficients.

Seasonal Distribution of Sediment concentration

The variability of TSM in the Hooghly estuarine region is dynamic in nature with maximum sediment load prevalent during the monsoon season followed by the post monsoon and minimum concentration are observed during the pre-monsoon season (Chacko and Jayaram, 2017). This seasonal variability is influenced by the monsoonal discharge through the Ganges-Hooghly river systems. Huge sediment load is transported through the river discharge and get deposited in the river channel. The typical shape of the estuary together with the activities like dredging and lengthening of the channel would result in bank erosion and enhances the TSM concentration.

The TSM concentration for the pre-monsoon (Fig. 2) is relatively low compared to the other seasons due to the negligible river runoff and precipitation during this season. The maximum concentration is observed to be confined to a few regions within the Hooghly estuary. Most of the regions within the estuary is prevailed by TSM values less than 50 g m^{-3}. TSM concentration is very low in the adjoining Sundarbans region when compared to the Hooghly river estuary. The reason for this distinct patter of TSM is attributed to the lack of runoff into the tide dominant creeks of the region unlike the estuary where river runoff forms a major source for the sediment load.

During the monsoon season however, the higher TSM concentration (>180 g m^{-3}) is observed (Fig. 3), which is due to the heavy river discharges resulting from the monsoonal rainfall. The region is dominated by cloud cover and this hampers the satellite measurements as evident from the Fig. 3 during this season. The limited region devoid of clouds clearly depicts a thick plume of sediments at the mouth of the estuary.

The post monsoon season is prevailed by moderate concentration of TSM with higher values (~ 100 g m^{-3}) confining to the estuarine region alone and lesser values (<100 g m^{-3}) in the adjoining Sundarbans region (Fig. 4). The post-monsoonal TSM concentration is lesser than during monsoon season and higher than during pre-monsoon season.

Impact of tides on the suspended sediment distribution

The impact of tides on the sediment distribution is assessed by using tide gauges available at two locations (Digha and Garden Reach, obtained from INCOIS) and synchronizing with the satellite overpass time. Tide data were segregated into two types *i.e*. Flood and Ebb tide. Flood tide is the rising tide in which direction of the tidal current is from the ocean to river and ebb tide is lowering tide in which direction of the tidal current is from river to ocean. Segregation of tidal data is carried out using slope on the tidal data. Tide is flood type if the slope of tangent on tide data is positive and tide is of ebb type for negative slope of tangent. Daily TSM data from 2016-2018 were segregated into 'Ebb tide' and 'Flood tide' scene by means of slope of the tide at the time of satellite overpass spell. Yearly mean composite image is derived for TSM during ebb and flood tide time for analysing effect of flood and ebb tide on TSM for the study area. From the analysis it is observed that the influence of tide is more pronounced in the spatial extent of the TSM. It can be seen from the Fig. 5 that the TSM offshore extent is more (21.25°N) during Ebb tide, while TSM offshore extent is less (21.5°N) and during flood tide.

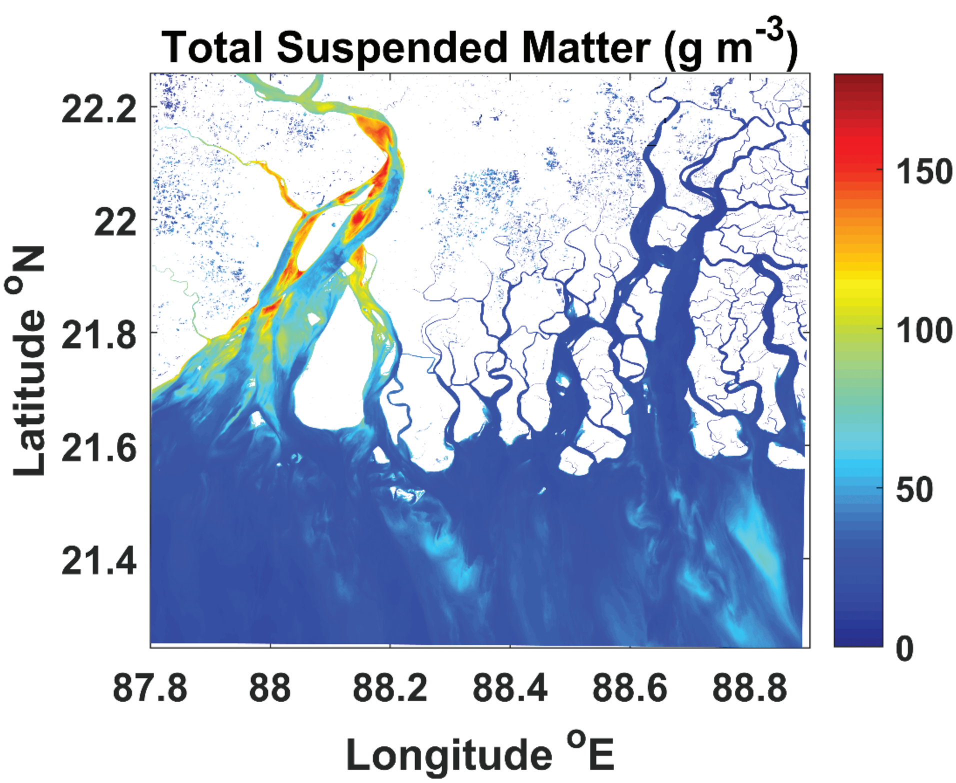

Fig. 2. Total suspended matter (TSM) in the Hooghly estuary and Sundarbans during pre-monsoon Season.

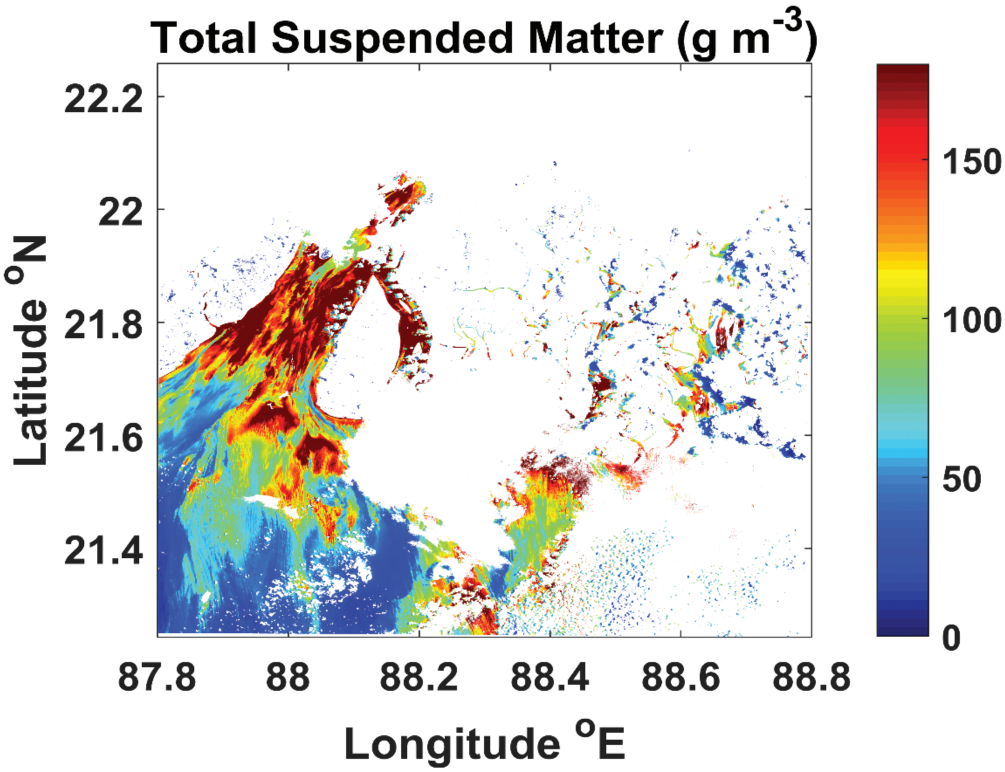

Fig. 3. Total suspended matter (TSM) in the Hooghly estuary and Sundarbans during monsoon season.

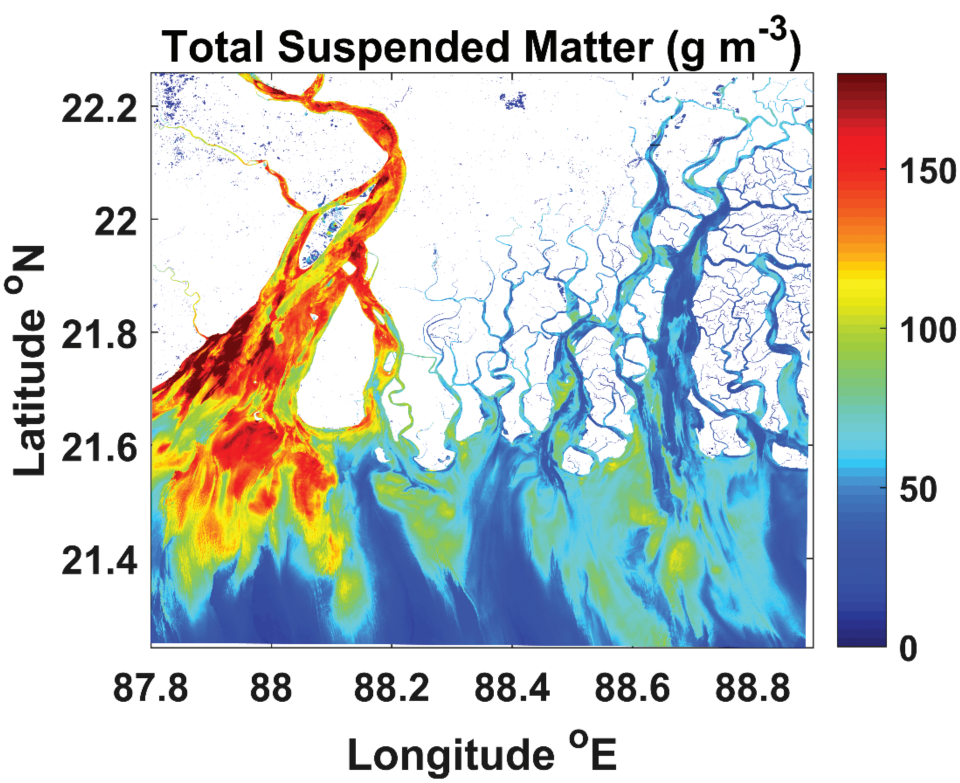

Fig. 4. Total suspended matter (TSM) in the Hooghly estuary and Sundarbans during post-monsoon season.

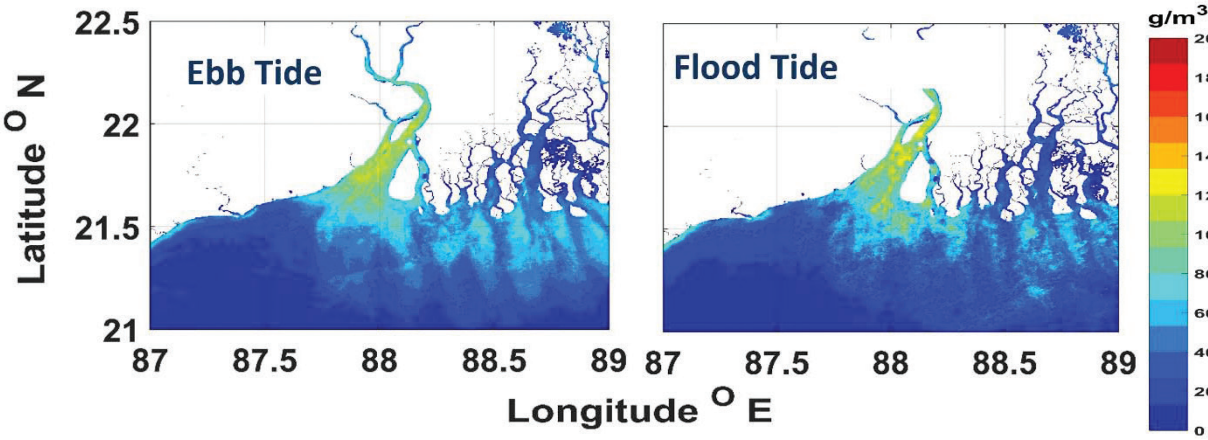

Fig. 5. Total suspended matter distribution during 'Ebb' and 'Flood' tides.

Conclusion

Monitoring and assessment of suspended sediments is carried out across various coastal regions of the world using different methods, ranging from the traditional in situ samplings to satellite observations and model simulations. Traditional *in situ* methods are insufficient to map the complex dynamics of suspended sediments and therefore remote sensing approaches for sediments studies are gaining importance. In the present study an attempt is made to ascertain the dynamics of sediments in the Hooghly Estuary and its variability with respect to the tides in the prevailing region. TSM is mapped using satellite data in the present study. The analysis of seasonal variability of TSM revealed that TSM concentration is least observed in the pre-monson season and highest in the monsoon season. Moderate concentration of TSM values is observed during the post-monsoon season. From the investigation of tidal influence on TSM, it is observed that the offshore spread is higher during Ebb tide phase and offshore spread is less during the Flood tide phase in the study region.

Acknowledgements

The authors gratefully acknowledge the Land Processes Distributed Active Archive Center (LPDAAC) USGS for making available the MODIS MYD09GQ andLandsat 8 / OLI data.Daily tide gauge data for Digha and Garden Reach are obtained from INCOIS. Sincere thanks are due to Dr. D. Dutta, General Manager, RRSC-East for his motivation and guidance during the work. Chief General Manager, RCs, and the Director, NRSC are thanked for the necessary support provided during the work.

BIBLIOGRAPHY

Adams, Jr. C. E. and Weatherly, G. L. (1981). Some effects of suspended sediment stratification on an oceanic bottom boundary layer. *Journal of Geophysical Research: Oceans* **86:** 4161-4172.

Chacko, N. and Jayaram, C. (2017). Variability of total suspended matter in the northern coastal Bay of Bengal as observed from satellite data. *Journal of Indian Society of Remote Sensing* **45:** 1077-1083.

Chen, S., Han, L., Chen, X., Li, D., Sun, L. and Li, Y. (2015). Estimating wide range total suspended solids concentrations from MODIS-250m imageries: an improved method. *ISPRS Journal of Photogrammetry and Remote Sensing* **99:** 58-69.

Doerffer, R., Fischer, J., Stössel, M., Brockmann, C. and Grassl, H. (1989). Analysis of thematic mapper data for studying the suspended matter distribution in the coastal area of the German bight (North Sea). *Remote Sensing of Environment* **28:** 61-73.

Miller, R. L. and McKee, B. A. (2004). Using MODIS Terra 250 m imagery to map concentrations of total suspended matter in coastal waters. *Remote sensing of Environment* **93:** 259-266.

Mukhopadhyay, S. K., Biswas, H., De, T. K. and Jana, T. K. (2006). Fluxes of nutrients from the tropical river Hooghly at the land-ocean boundary of Sundabans, NE coast of Bay of Bengal, India. *Journal of Marine Systems* **62:** 9-21.

Nechad, B., Ruddick, K. G. and Park, Y. (2010). Calibration and validation of a generic multisensory algorithm for mapping of total suspended matter in turbid waters. *Remote Sensing of Environment,* **114:** 854-866.

Sadhuram, Y., Sarma, V. V., Murthy, T. V. R. and Rao, B. P. (2005). Seasonal variability of physiochemical characteristics of the Haldia channel of Hooghly estuary, India. *Journal of Earth System Science* **114:** 37-49.

Stumpf, R. P. (1987). Application of AVHRR satellite data to the study of sediment and chlorophyll in turbid coastal water. US Department of Commerce, National Oceanic and Atmospheric Administration, National Environmental Satellite, Data, and Information Service.

Tassan, S. (1994). Local algorithms using SeaWiFS data for the retrieval of phytoplankton, pigments, suspended sediment, and yellow substance in coastal waters. *Applied Optics* **33:** 2369-2378.

Trinh, R. C., Fichot, C. G., Gierach, M. M., Holt, B., Malakar, N. K., Hulley, G. and Smith, J. (2017). Application of Landsat 8 for Monitoring impacts of wastewater discharge on coastal water quality. *Frontiers in Marine Science* **4:** 329.

Vermote, E. F., El Saleous, N. Z. and Justice, C. O. (2002). Atmospheric correction of MODIS data in the visible to middle infrared: first results. *Remote Sensing of Environment* **83:** 97-111.

Yang, X., Sokoletsky, L., Wei, X. and Shen, F. (2017). Suspended sediment concentration mapping based on the MODIS satellite imagery in the East China inland, estuarine, and coastal waters. *Chinese journal of oceanology and limnology* **35:** 39-60.

Agricultural Development in Coastal Regions: Socio-Economic, Gender and Policy Issues

SOUVIK GHOSH* and N.P. DARSHAN*

Department of Agricultural Extension, Institute of Agriculture, Visva-Bharati University, Sriniketan, Birbhum, West Bengal- 731236, India

**Corresponding author:* Email: souvik.ghosh@visva-bharati.ac.in; npdarshan24@gmail.com

The coast is the interface between the land, ocean and atmosphere. The coastal zone encompasses the land area being significantly influenced by the sea, and the sea is notably influenced by the land. This complex space is also strongly impacted by human activity (World Ocean Review, 2010). Coastal areas can be defined as the interface or transition areas between land and sea including large island lakes. Since the coastal area formation and morphology are influenced by natural phenomena like sediment supply from rivers or the sea and anthropogenic activities, the exact delineation of coastal areas is difficult. However, the area within 60 to 200 kilometers of the shore level which may include coastal flood plains, coastal forest called mangroves, seagrass meadows, estuaries, coral reefs, marshes, and tide flats (coastal areas affected by the rise and fall of the tide), beaches, dunes and coral reefs.

Climate-related hazards like rising sea levels, storm surges, higher flood, coastal erosion, seawater intrusion, increasing surface temperatures, etc. lead to a series of socio-economic impacts in the coastal zones. These include reduced agricultural productivity, loss of property and coastal habitats, loss of tourism, recreation, transportation and industry activities (Kumar and Taylor, 2015). Besides, the non-climate stressors like urban growth, migration, land-use change, pollution, gender issues, etc. are often found as the drivers of changes in coastal agriculture, which have an impact on the sustainability of food security in coastal areas (Moser *et al.*, 2014; Lambin *et al.*, 2001).

Significance of Coastal areas

Coastal areas are some of the most productive and biologically diverse areas. Of the 13,200 known species of marine fish, almost 80 per cent are coastal. The world's oceans play a crucial role in maintaining the health of the planet's ecosystems and serve as a valuable current and future food source for humankind. The oceans provide the only means of subsistence for many communities around the world, particularly the expanding coastal populations (UN Atlas of the Oceans, 2010).

A large portion of the world population lives in flat coastal areas that can drastically change their shape within a short time. The populations in coastal zones are growing faster than in any other region on Earth. Favourable biophysical and climatic conditions, and the scope for communication and navigation, have been encouraging human settlement in coastal areas since prehistoric times and 44 per cent of the world's population live within 150 kilometers of the coast (UN Atlas of the Oceans, 2010). About 257 counties have their boundaries along the coastline (https://www.listofcountriesoftheworld.com/coastline.html). More than 45 per cent of the world's population lives and works in coastal areas. Coastal region is heavily populated with nearly 250 million people living within 100 km of India's coastline (Velmurugan *et al.*, 2017).

The coastal zones of the Earth are extremely diverse and tremendously important, not only for concentration of population but also because of high productivity of its ecosystems, exploitation of natural resources, development of various industries, recreation and tourism, fertile land due to sedimentation from river systems, etc.

Agricultural Development in Coastal Regions

Coastal areas provide excellent soil and climatic conditions for agriculture. They play an important role in the economy, providing food and raw material for industry. Agricultural products find markets in tourism and craft, while port facilities facilitate the trade. The coastal areas associated with alluvial accumulation plains generally have deep, relatively flat, fertile soils and benefit from a substantial supply of water from surface and/or subsurface ground water sources. The stable sea currents exert a moderating influence on agriculture by providing milder and more humid climatic conditions which favour the production of several unique crops in the region.

In the countries associated with small islands, agricultural production makes an extremely important contribution to the local economy or national agricultural production. In countries such as Egypt and Bangladesh, the river deltas, with their fertile alluvial soils, play a major role in the agriculture sector (Scialabba, 1998). However, coastal agriculture faces several challenges due to primary driving forces that include short-term weather, long-term climate, seasonal changes in sea level and tides. The temporal ocean/sea activities are producing saline air and water and the inundation and erosion of coastal land. Upstream activities can affect the quality and availability of water.

Farmers' interests and activities (both farm and non-farm), farmers' having limited flexibility in production decisions, their vulnerability to climate change and their decision making involving non-commercial considerations need to be considered while planning for coastal agricultural activities. The complexity of these factors makes farmers' participation important in coastal area planning that includes agricultural activities (Scialabba, 1998). Planning for agricultural development in coastal areas must consider special characteristics. Coastal agriculture includes a broad range of production activities (crops and livestock, fisheries), small to large commercial enterprises and both intensive and extensive production processes (intensive, extensive). It contributes to the local economy, social cohesion and the maintenance of the cultural traditions of a society. Coastal agriculture is governed by complex considerations among which socio-economic factors are very important. Last but not least, gender is essential to take into account.

Planning for effective and sustainable development must adopt integrated approach to soil and water conservation. Piecemeal approaches to reclaim location specific problems for short term gains lead to adverse impacts including seawater intrusion into inland areas, massive loss of mangroves, coral reefs, sea grass and various other aquatic and animal species, sedimentation of erosion, tidal flooding, subsidence of land, etc. (Sen, 2016).Therefore, for the effective agricultural development in coastal regions, the detailed examination of the factors influencing the agriculture sector is very important.

Agriculture in Indian Coastal Regions

The Indian peninsula is endowed with heterogeneous landforms and variety of climatic conditions which provide high plateau, open valleys, rolling upland, fertile plains, swampy lowlands, coastal areas, and barren deserts (Velmurugan *et al.*, 2017). India has a long coastline of about 7516.6 km of which 5,422.6 km is in the mainland and that includes eight states and three union territories. Both the west and east coastal regions are interspaced by several river systems which bring fertile silt and water from the mountain ranges. This region offers great potential in terms of high productivity of its ecosystems. However, the concentration of population, exploitation of natural resources, development of traditional resource-based and secondary industries, discharge of waste effluent and sewage, increasing load on harbours and above all petroleum and natural gas exploration activities are growing concerns in coastal regions.

The predominant climatic conditions of the majority of the coastal sub-regions in India falls under the hot and humid or sub-humid condition with normal annual rainfall over 1000 mm. About 80% of the rainfall occurs during June to September in west coast as well as in coastal areas of the states like West Bengal, Odisha and Andhra Pradesh in east coast; however, in Tamil Nadu, 70 per cent of its annual rainfall happens during October and November.

The salinization of surface soil in several areas especially during the dry season in the presence of poor-quality groundwater is a problem in coastal areas. In general, the soils of coastal areas are deep to very deep, imperfectly to poorly drained, sandy to fine loamy to fine in texture. The sandy shores are covered partly with water during high tides and stormy periods. The soils are calcareous, slightly to moderately saline and alkaline.

In coastal regions, delineation of homogenous land units and understanding the problems and potentials of each unit are imperative to explore the possibilities for farming with improved efficiency and productivity. In this context, the characterization of such a large stretch of coastal areas involves systematic appraisal and grouping of relatively homogenous areas in terms of soil, climate, physiography and conducive moisture availability periods. The coastal region of India is divided into three Agro-Ecological Regions (AER) namely, Gujarat plain/western plain hot arid eco-region, West Coastal plain, hot humid-per humid eco-region, and East Coastal plain, hot sub-humid to semiarid eco-regions. The three AER is subdivided into 12 AESR incorporating details about the climate, soils, area and districts, land use and constraints (Velayutham *et al.*, 1999).

The coastal region is potentially characterized by good rainfall, surface and groundwater resources, diversified and rich biodiversity, mostly of deltaic soils, humid to sub-humid conditions suitable for cultivation of a variety of crops. Rice is the main food crop grown besides plantations of bananas, coconut, areca nut, cashew nut and rubber mostly in the western coast and betel nut in many places in the deltas. In many places along with the coastal plain double cropping with rice as the main crop is commonly practiced. With availability of irrigation, the second crop of rice is taken. After the monsoon, wells, rivers and streams are used to lift water for irrigation. In unirrigated fields, pulses and spices are planted. Plantation crops are a very important component of the western coast and islands. Despite the good potential for agriculture, the yield gap for various crops varies from 0.5 to 2.6 t/ha and the cropping intensity ranges from 140 per cent to 210 per cent (Velmurugan *et al.*, 2017).The major crops grown are vegetables, fruit crops in Maharashtra; soybean, chickpea, fruit crops, groundnut and sugarcane in Karnataka; pepper, banana, coconut, coffee and turmeric in Kerala; cotton, cashew banana, mango, guava, coconut in Tamil Nadu and banana in Andhra Pradesh and Odisha (Ramesh *et al.*, 2008).

Socio-Economic Factors

Agriculture has both positive and detrimental effects on the coastal environment. Coastal Biodiversity has been encouraging human settlement since prehistoric times. Land-based and sea-based natural resources are the foundations of millions of people for their livelihood in the coastal regions. Favourable climatic and biophysical conditions and abundant resource base, the scope for navigation and trading has made coastal areas one of the potential areas of development. Coastal areas make the hub of economic activities such as industry, oil and gas extraction, mining, ocean transport, shipping, tourism, coupled with agriculture and allied activities. These potential economic activities have been encouraging the people from economically deprived areas to migrate and settle in the coastal regions for subsistence, employment, housing, energy, food, water, and other goods and services. These diversified economic activities are often dependent on coastal resources and, as economic diversification increases and makes the component sectors more interdependent, conflicts over natural resources and the environment will tend to develop.

In many countries, population in coastal areas are growing faster than those in non-coastal areas. This is a concern because population growth and the activities associated with it can degrade coastal and marine ecosystems (Cohen, 1997). In some countries, heavy use of fisheries has reduced endemic coastal fish stocks from 10 per cent to 30 per cent of the supply that existed 30 years ago (Hongskul, 1999). Human intervention has degraded about half of the world's wetlands by the 20th century, and nearly 50 per cent of all mangroves and nearly 60 per cent of the world's coral reefs are seriously degraded in some cases beyond recovery or threatened (FAO, 2001). Fish stocks, freshwater, soils and beach sands are often overexploited, at great economic and ecological cost.

Coastal water quality and biodiversity are greatly impacted by regional land use, especially, agricultural activities causing erosion and runoff of agricultural chemicals into coastal water bodies. The sewage waste produced from the overcrowded towns and cities situated on the coastal banks is polluting the mouth of the rivers. Agriculture's negative practices, such as irrigation practices, agrochemicals and silting of coral reefs and ports cause pollution for fisheries and marine biodiversity and negative influences on other sectors. Coastal eutrophication has increased globally with agriculture as the leading source of nitrogen pollution in coastal marine ecosystems (Howarth, 2008).

Diversification of freshwater river sources approaching the sea for irrigation purposes and discharge of non-point pollutants for agricultural sectors have been disturbing the coastal water bodies. Agriculture runoff, which mostly brings suspended organic and mineral matters, inorganic nutrients causing eutrophication (N, P extra loads) and xenobiotic substances causing toxic effects on the natural ecosystems.

The agriculture and allied sectors are contributing a share of 15.87 per cent total Gross Value Added (GVA) portion of Indian economy and employing 59 per cent of the total workforce (Ministry of Statistics and Programme Implementation, Govt. of India, 2020), to which the fisheries and coastal agriculture are contributing at the rate of 0.91 per cent and 5.23 per cent GVA, respectively.

Agriculture is also influenced by the positive and negative interactions with companion sectors. Agriculture may provide raw materials to industry located in coastal areas and may therefore have considerable economic significance. In particular, fostering the linkage between agriculture and tourism offers opportunities in both sectors for demand and supply of food, beverage and employment. Negative influences are competition for land, water, capital, labour and pollution originating from coastal or outside sectors.

In the Indian coastal region, various economic activities and human settlement compete with agricultural land use causing a decrease in available land for agricultural purposes. This region is also located in areas most vulnerable to natural disasters, areas that are already subject to periodic flooding and various types of land degradation. Ghosh *et al.* (2017) worked out resilience of agriculture in the districts of eastern Indian state West Bengal, where, South 24 Parganas, a coastal district showed more vulnerability with lesser resiliency in the event of climatic disasters like flood and cyclone. Climate change-induced sea-level rise is a major threat to the country as the 73 coastal districts (out of a total of 593) have a share of 17% of the national population, with nearly 250 million people living within 50 km of the coastline (Central Water Commission, Govt. of India, 2017). The sea level rise by 4.8 cm is recorded; by 2050 and 2100, sea level is projected to rise by 16 cm and 32 cm, respectively, as mentioned by V. Selvam, Executive Director of Chennai-based M.S. Swaminathan Research Foundation while speaking at a media workshop on climate change, climate justice and resilience in the Bay of Bengal region that was organised by Internews' Earth Journalism Network and The Third Pole, a sister portal of India Climate Dialogue (Jamwal, 2019).

More than seven million coastal families of fishers and farmers are affected due to the rising sea level. The most vulnerable areas are the Mumbai coast, Kutch region, southern Kerala and Lakshadweep islands in the west coast; and the Ganga delta, Cauvery delta, Krishna and Godavari deltas in the east coast (Jamwal, 2019).There are several physical impacts of sea-level rise. For instance, submergence of low-lying areas, inundation of seawater in non-saline areas due to altered tides, increased salinization of soil and water, coastal lands turning into the wasteland, and loss of livelihood to fishers and farmers. Heavy exploitation of groundwater coupled with changes in land configuration in many coastal areas has resulted in seawater intrusion and the development of high soil salinity. As a result, this has become one of the impediments for improving farm production even though the agro-climatic condition is suitable for different crops and farming systems. In salt affected regions of western Gujarat, there is a decrease in farm production, resource productivity leading to shifting of labour from agriculture and income inequality. The small and marginal farmers are worst affected and shifting to industries and farm labour for livelihood (Khunt *et al.*, 2010). In coastal areas of Indian state of West Bengal, the younger generations are shifting towards other livelihood options as low producing agricultural sector is not fulfilling the livelihood needs. Hence the demand for labour is increasing during the peak cropping activity (Bandopadhyay *et al.*, 2010).

The study undertaken by Patnaik and Narayanan (2009) built a vulnerability index and rank the various coastal districts of highly vulnerable states (Andhra Pradesh and Odisha) in terms of their performance on the index. The analysis carried out pointed out that the clusters of districts of poor infrastructure and demographic development were also the regions of maximum vulnerability. Some districts exhibited very low rate of growth in infrastructure, alongside a high growth rate of population. Also, these districts showed a higher density of population. Hence any occurrence of extreme events is likely to be more catastrophic in nature for the people living in these districts.

People in the coastal districts of the eastern Indian state of Odisha are increasingly suffering from the effects of climate change induced natural disasters that is seriously affecting the rural households, who are mainly dependent on natural resources for their livelihood. Despite the high productivity of the area in agriculture and fisheries in past years, population pressure and adverse weather conditions due to climatic change has been damaging the coastal ecosystem which is pushing the rural households below the poverty line (UN Environment Program, 2019).

Gender Issues

The vulnerable population of coastal regions faces restrictions in accessing the coastal water to the full extent. Women usually have different access to and control over land and water in coastal zones. Being less visible in their work, women are also less likely to have access to decision-makers or to be part of decision-making process regarding management of natural resources. Poor women depend mostly on fish catching and related activities close to the shore and use the catch to feed their families; whereas, men typically engage in large-scale commercial fishing offshore or in major inland water bodies. Operating on a smaller scale, women who fish earn only 40 to 50 per cent of what men earn for fishing (FAO, 1998).

In many coastal environments, both men and women play important but different productive, economic and social roles. There are differences in resource use patterns, access to land, natural resources, equipment, labour, capital, outside income, and education, and in the control that women and men exert over these resources (Ingen *et al.*, 2002).

The main issue that arises from impacts of climatic change on gender roles in the coastal regions is the out-migration of rural people to urban areas after occurrence of any natural disasters. Regarding migration, males are more likely to go to cities to earn money from labour-intensive and non-agricultural jobs. The nature of non-agricultural jobs in the cities itself attracts mostly the men and the reproductive role of women restricts them from migrating to cities. Consequently, females tend to stay at home to raise children and take care of household activities. The migration of men in the event of climate change and poverty are the main reasons for the increase in women in agriculture, both as cultivators and labourers (Pattnaik *et al.*, 2017). However, women from male-migrant families face difficulties when trying to continue farming sustainably. It was observed that women face exclusion from extension services and found it difficult to prepare the land and seedbeds, irrigate the land, spray pesticide and haul rice; duties that are usually performed by men in the coastal Mekong Delta in Vietnam (Paris, 2009). In a changing climate, agriculture is not capable of sustaining the livelihood in coastal areas alone due to its low productivity. Women have been forced to undertake subsistence agriculture (the rearing of small livestock, home gardening and beekeeping) to produce food for survival because of the insufficient income of the men from fishing activities.

In few seascapes, which could be demarcated as terrestrial coast forest, mangrove forest, seagrass beds, coral reef and deep sea, the activities were mainly gendered. Men dominated activities like building material collection, medicine and fertilizers collection, fishing activities, tourist activities and women were involved in wide variety of activities like agriculture, firewood collection, fruit collection, building collection, collection of twigs for local fish trap, lime making, collection of sticks for seaweed farming, rope and charcoal making, firewood collection, invertebrate collection, seaweed mariculture etc., which indicated a shift of gender role from reproduction to productive roles. However, the access and control over resources, decision making and management power were still androcentric (Torre-Castro *et al.*, 2017). The common managerial discourses have been using the terminologies such as stakeholders and appropriators or fishermen and middlemen representing men's involvement. Therefore, in general, the phrase coastal marine management is often replaced by gender blind natural resource management (Agarwal, 2010).

In the coastal districts of Odisha, India, the impact of climate changes on men and women is different. The structural inequality coupled by wealth status, ethnicity, age and location are defining the impact levels between men and women in the sense that poor women, children, elderly and disabled were worst affected and women were found to be more exposed to social tensions, malnutrition, and increased workload. Nevertheless, both men and women adopted different coping mechanisms for climate emergencies. Men were leaving the villages for seasonal employment posing the women to work for additional income generation activities along with reproductive role. The women were also exposed to animal attacks and fuel conflicts with forest officers and sometimes even to sexual harassment (UN Environment Program, 2019).

Policy Issues and Guidelines

Three decades ago, in 1988, data on coastal saline soils were calculated, which came out with a figure of about 3.1 million ha saline soil along India's coastal tract of West Bengal, Odisha, Andhra Pradesh, Puducherry, Tamil Nadu, Kerala, Karnataka, Maharashtra, Gujarat, Goa, and Andaman and the Nicobar Islands. It included about 0.57 million hectares of the salt-affected area under mangrove forests. Since then, this figure has not been updated though coastal salinity has increased rapidly (Jamwal, 2019).

Planning for coastal agricultural activities must take into considerations the wide range of farmers' interests and activities, including non-farm activities, the limited involvement of farmers in production decisions, their high vulnerability to adverse environmental change and the importance of non-commercial considerations in their decision-making. The complexity of these factors makes participation or consultation particularly important in coastal area planning, where it impinges on agricultural activities. In particular, planning in coastal areas must account for such special characteristics of agriculture as given below.

It should include a broad range of activities with a variety of types of product (crops and livestock, food and industrial raw materials), enterprises (from smallholdings to large commercial enterprises) and production processes (intensive, extensive).

It should make a variety of contributions to the local economy, social cohesion and the maintenance of the cultural traditions of a society.

Since it is dependent on natural growth processes and, to a greater or lesser extent, on land and its associated natural resources and environment, sustainable agricultural policies are therefore needed to minimize the negative impacts of inland agriculture in coastal areas.

At least 107 of the world's 134 developing nations having coastal areas are involved in some type of ICM (Integrated Coastal Management) effort at the national or subnational level (Sorensen, 2000). In general, the most successful ICM efforts share several characteristics in common (Cicin-Sain and Knecht, 1998).

Engaging multiple stakeholders, including representatives from all levels of government, NGOs, indigenous groups, communities, and the private sector in planning of coastal agriculture interventions is needed. The planning should also ensure the establishment of clear and objective oriented management process, formalized guidelines and funding mechanisms, informed decision-making framework incorporating social, environmental, and economic data, decentralized policy formulation and programme development, community-based management initiatives to create community awareness and experience, build support, and provide information about regional or national programmes, capacity building of local institutions and experts through training, education, and applied research, strong outreach network to provide information and education to all levels of management, and regular collection of reliable data to measure the objectives of management endeavours.

Conclusion

Coastal area with a vast resource base is nurturing almost all the sectors of economy including agriculture. Even though coastal agriculture is a primary occupation of local population, it is under the threat of competition by other secondary and tertiary sectors. The major challenges to sustainable coastal agriculture are climatic and non-climatic stressors such as temperature increases, rainfall fluctuations, population growth and migration, pollution, land-use changes and inadequate gender-specific strategies, etc., which are combinedly boosting the threats to a greater extent resulting in reduced agricultural productivity, land-use change, pollution, loss of property and coastal habitats, loss of tourism and forced migration. These changes also impacting the socio-economic aspects, gender mainstreaming and policy decisions. The issue of coastal agricultural adaptation to climate change needs to be addressed through increased farmers' participation for sustainable farm livelihood in coastal regions. The coastal agriculture could be sustained through blending farmer perceptions, adaptation options, gender-specific participation and integrated coastal resource management into policy advocacy. Hence, it is important to develop policy guidelines by addressing all the factors hampering the process of agricultural development in coastal regions.

BIBLIOGRAPHY

Agarwal, B. (2010). *Gender and green governance: the political economy of women's presence within and beyond community forest*, Oxford University Press, Oxford; New York. p. 488.

Bandopadhyay, B. K., Mandal, S., Burman, D. and Sarangi, S. K. (2010). Soil and water management options for enhancing agricultural productivity in coastal area of West Bengal. *Journal of Indian Society of Coastal Agricultural Research* **28(1):** 1-7.

Central Water Commission, Ministry of Water Resources, River Development & Ganga Rejuvenation, Govt. of India (2017). *A report on Problems of Salination of Land in Coastal Areas of India and Suitable Protection Measures*. Hydrological Studies Organization, Central Water Commission, New Delhi.

Cicin-Sain, B. and Knecht, R. (1998). *Integrated Coastal and Ocean Management: Concepts and Practices*, Washington, DC: Island Press.

Cohen, J. E. (1997). Population, economics, environment and culture: an introduction to human carrying capacity. *Journal of Applied Ecology* **34:** 1325-1333.

Food and Agriculture Organization (FAO). (1998). *Coastal Zone Management and Equality between Women and Men*. Rome: FAO.

Food and Agriculture Organization (FAO). (2001). *World Fisheries and Aquaculture Atlas CD-ROM*. Rome: FAO.

Ghosh, S., Mahato, K., Gorain, S., Das, U. and Mondal, B. (2017). Resilience of agriculture reducing vulnerability to climate change in West Bengal. *Current Advances in Agricultural Sciences* **9(2):** 170-177.

Hongskul, V. (1999). *Into the Next Millennium*: Fishery Perspective. RAP Working Paper Series 1/3, Food and Agriculture Organization of the United Nations Regional Office for Asia and the Pacific Bangkok (www.fao.org/DOCREP/003/x6947E/X6947E00.htm)

Howarth, R. W. (2008). Coastal nitrogen pollution: A review of sources and trends globally and regionally. *Harmful Algae* **8(1):** 14-20.

Ingen, Van T., Kawau, C. and Wells, S. (2002). *Gender Equity in Coastal Zone Management: Experiences from Tanga, Tanzania*. IUCN Eastern Africa Regional Programme.

Jamwal, N. (2019). *Rising sea forces villagers to abandon rice farming*, India Climate Dialogue. (Rising sea forces villagers to abandon rice farming - India Climate Dialogue)

Khunt, K. A., Shiyani, R. L. and Golakiya, B. A. (2010). Socio-economic impact of salinity on agriculture in western Gujarat. *Journal of Indian Society of Coastal Agricultural Research* **28(1):** 79-84

Kumar, L., Taylor, S. (2015). Exposure of coastal built assets in the South Pacific to climate risks. *Nature Climate Change* **5:** 992-996.

Lambin, E. F., Turner, B. L., Geist, H. J., Agbola, S. B., Angelsen, A., Bruce, J. W., Coomes, O. T., Dirzo, R., Fischer, G., and Folke, C. (2001). The causes of land-use and land-cover change: Moving beyond the myths. *Global Environmental Change* **11:** 261-269.

Moser, S. C., Davidson, M. A., Kirshen, P., Mulvaney, P., Murley, J. F., Neumann, J. E., Petes, L., and Reed, D. (2014)). *Coastal zone development and ecosystems*. In: Climate Change Impacts in the United States: The Third National Climate Assessment; Melillo, J.M., Richmond, T.T.C., Yohe, G.W. (Eds.), U.S. Global Change Research Program: Washington, DC, USA, pp. 901-954.

Paris, T. R., Chi, T. T. N., Rola-Rubzen, M. F., Luis, J. S. (2009). Effects of out-migration on rice-farming households and women left behind in Vietnam. *Gender Technology and Development* **13:** 169-198.

Patnaik, U and Narayanan, K. (2009). Vulnerability and climate change: an analysis of the eastern coastal districts of India. Munich Personal RePEc Archive. https://mpra.ub.unimuenchen.de/22062/1/ MPRA_paper_22062.pdf.

Pattnaik, I., Lahiri-Dutt, K., Lockie, S. and Pritchard, B. (2017). The feminization of agriculture or the feminization of agrarian distress? Tracking the trajectory of women in agriculture in India. *Journal of the Asia Pacific Economy* **23:** 138-155.

Ramesh, P., Panwa, N. R., Singh, A. B. and Ramana, S. (2008). Effect of organic manures on productivity, soil fertility and economics of soybean–durum wheat cropping system under organic farming in vertisols. *Indian Journal of Agricultural Sciences* **78:** 1033-1037.

Scialabba, Nadia (Ed.). (1998). *Integrated coastal area management and agriculture, forestry and fisheries*. *FAO Guidelines*. Environment and Natural Resources Service, FAO, Rome. 256 p.

Sen, H. S. (2016). Coastal Zones: Ecology and climate change need concerted attention for sustained productivity. *Journal of Indian Society of Coastal Agricultural Research* **34(1):** 1-12.

Sorensen, J. (2000). Baseline 2000: Background Report (www.uhi.umb.edu/b2k/baseline2000.pdf).

Torre-Castro, M., Fröcklin, S., Börjesson, S., Okupnik, J. and Jiddawi, N. S. (2017). Gender analysis for better coastal management – Increasing our understanding of social-ecological seascapes. *Marine Policy* **83:** 62-74.

UN Environment Program, (2019). *Women as climate action ambassadors in coastal districts of India's Odisha State*. Ecosystem and biodiversity. Women as climate action ambassadors in coastal districts of India's Odisha State (unenvironment.org)

Velayutham, M., Mandal, D. K., Mandal, C. and Sehgal, J. (1999). *Agro-Ecological Subregions of India for Planning and Development*. NBSS and LUP, Publication. No. 35, pp. 372.

Velmurugan, A., Swarnam, T. P., Ravisankar, N., Subramani, T., Swain, S. and Jaisankar I. (2017). *Organic Agriculture in Coastal Areas*. In: Towards Organic Agriculture, Gangwar B. and Jat N. K. (Eds.), Today & Tomorrow's Printers and Publishers, New Delhi - 110 002, India, pp. 87-108.

World Ocean Review: Living with the oceans. (2010). Maribus GmbH, Hamburg, Germany.


NABARD
ATM
Transforming Rural India,
Transforming Lives
India's apex development bank, NABARD promotes sustainable and equitable agriculture and rural development through participative financial and non-financial interventions, innovations, technology and institutional development for security prosperity.
Taking Rural India >> Forward
www.nabard.org
/nabardonline