Manual on Best Practise of Seaweed cultivation : Kappaphycus alvarezii

CRK Reddy
Institute of Chemical Technology, Mumbai

Karuppanan Eswaran
Central Salt and Marine Chemicals Research Institute

Ganesan Meenakshisundaram
Central Salt and Marine Chemicals Research Institute

Sangaiya Thiruppathi
Central Salt and Marine Chemicals Research Institute

Manual on Best Practise of Seaweed cultivation : *Kappaphycus alvarezii*

CSIR-CSMCRI

C.R.K. Reddy
K. Eswaran
M. Ganesan
S. Thiruppathi
Vaibhav A. Mantri

CSIR - Central Salt & Marine Chemical Research Institute
Bhavnagar - 364002, Gujarat.
CSMCRI - Marine Algal Research Station,
Mandapam Camp - 623519, Tamil Nadu.

Sponsored by : National Fisheries Development Board
Hyderabad - 500 052

Acknowledgement

First of all we would like express our sincere gratitude to Dr.Amitava Das, Director, CSIR-Central Salt & Marne Chemicals Research Institute (CSIR-CSMCRI) and to our former Director Dr.P.K. Ghosh for mooting the concept behind the manual and providing constructive ideas on developing the methods of seaweed cultivation.

We would like to specially thank to Dr.V.Veeragurunathan, Dr.Subir K.Mandal and Dr.Monica G.Kavale for sharing valuable information on cultivation of agarophytes.

The assistant rendered by our former technicians Mr.A.Sathakku, Mr.Jainullabudeen and Mr.Seeni Syed Ahemad and supporting staff Mrs.A.Luciyal & Mrs.S.Mallika during filed experiments is greatly appreciated. Many other research students and field assistants in the Division of Biotechnology &Phycology have extended support one form or other we would like to thank them collectively.

Our sincere thanks are also due to Mr.R.Baratharaja of MARS, Mandapam and all staff members of administrative, finance & purchase officesat CSMCRI, Bhavnagar for their co-operation and support which facilitated smooth executions of the field studies during standardization of the cultivation methods .

The publication of this manual would not have been possible without the generous funding from National Fisheries Development Board, Hyderabad

Foreword

In recent times, marine macroalgae (commonly known as seaweeds) drawing considerable attention globally as a renewable feed stock for various industrial applications. Commercial harvesting of seaweeds has reached new milestone with 27 million tones year^{-1} production (95% accounts to farming) with a market value of over US$ 4.8 billion (FAO, 2016).

CSIR-CentralSaltandMarineChemicalsResearchInstitute hasbeen actively pursuing the seaweedresearchfornearlyhalfacentury. This institute takes pride in being first for pioneering *Kappaphycus alvarezii* cultivation, heralding an era of commercial seaweed farming in India. Carrageenan - which is primarily obtained from this alga - by virtue of its distinctive gelling properties, is used as an emulsifier and thickener in diverse commodity products of daily need. The quest to explore more water and energy efficient processing technology led to invention of liquefying fresh seaweed biomass to obtain two products in an integrated manner, one being a granular residue rich in κ-carrageenan and the other being sap rich in potash and micronutrients (ca. 2 % w/v), with proven efficacy has provided a boost to commercial farming. India is fast emerging as an important center in Southeast Asia for *Kappaphycus alvarezii* production. The production has been substantially increased from 21 dry tonnes in 2001 to 1490 dry tonnes in 2013 with concomitant purchase value of <□ 4.5 to 35 Rs kg^{-1} (dry).

The commercial farming is now well established in Ramanathapuram District of Tamil Nadu. Given the fact that, there is low literacy in this area coupled with meagre self-employability, seaweed farming is paving the way for women and young entrepreneurs through organized Self Help Groups. There are over 50 SHGs currently engaged in seaweed farming and the activity has been subsequently extended to nearby coastal districts namely Pudukkottai and Tuticorin. It does not require land, water for irrigation and agriculture inputs such as fertilizer and pesticides. The techniques employed are simple, cost-effective, utilizes readily available material, does not require specialized skills and can be practiced at the individual farmer level with little training especially for women fisher-folk. The higher and more stable income to these women has proved to improve the living standards of their family, education to the children, health, and accessibility to better amenities. These accrued benefits are attracting more participation and offering opportunities for economic empowerment of women contributing positively toward reducing gender bias.

CSIR-CSMCRI in association with National Fisheries Development Board (NFDB), Hyderabad is trying to promote young fishermen as an entrepreneur from coastal villages across the country through successfully organizing trainings. The large-scale farming needs to be further strengthened and promoted by looking at potential socio-economic implication it offers for the inclusive economic growth in rural coastal settings. It would also help in the realization of the goal of doubling farmers' income by the year 2022.Nodoubt,downstream industries will comeup in due course.

I sincerely believe that this manual will help new participants to practice seaweed cultivation more effectively. On behalf of CSIR and our Institute, I convey our best wishes for the successful implementation of the project.

Amitava Das, FNA
J.C. Bose National Fellow
Director, CSIR- CSMCRI

Thanks to the scientific community of CSMCRI for starting research and development in seaweed, due to which, today we are in a stage where, by the end of the year, 40,000 rafts will be placed in the sea near Mandapam area of Tamil Nadu for cultivation of the seaweed and it is estimated that the number will go up to 1.5 lakhs. The scientists have developed a unique technology of liquefying the seaweed without adding any water and thereafter they have separated the solid from the liquid to obtain two products. The solid is the source of carrageenan for which seaweed was cultivated in the first place and the liquid - which is the plant sap - has been found to be a very useful plant nutrient rich in Potassium and organic growth promoting hormones. This sap has been used in a variety of crops such as sugarcane, paddy, maize, pulses and several fruits and vegetables. The productivity increase has been in the range of 12% to 30% in different regions as per studies conducted by different institutions. This highly innovative process of producing two useful products from the fresh harvest of the seaweed is being done for the first time in the world.............

Honourable President

Dr. APJ Abdul Kalam

Technology Day Address on May 11, 2006

Manual on best practice of seaweed cultivation: *Kappaphycus alvarezii*

Introduction

Kappaphycus alvarezii (Doty) Doty (= *Eucheuma\striatum = Kappaphycus striatum*), which weregrown originally in Japan (Mairh et al., 1995)were initially cultured in Okha, west coast ofIndia. Acclimatization and large scale cultivationof this alga was achieved on the coast of Mandapam, south east coast of India, during 1995to 1997.. CSMCRI (Central Salt and Marine Chemicals Research Institute – Marine Algal Research Station - CSIR), Mandapam commenced farming on R&D basis and transferred the technology for the first time India and being cultivated in Tamil Nadu since 2001. PepsiCo India Holdings Private Limited, Gurgoan is deeply involved in the cultivation of this economically important seaweed from 2001 to June. 2008, which got the technology from CSMCRI in 2001. This company was successful in expanding cultivation activities to Tamil Nadu with 15000 bamboo rafts occupied 9 km linear coastline from Mandapam to Rameswaram in Ramanathapuram district and mono line method was adopted in Pudukkottai district in12 hectares area. Currently there are several companies such as MARINE LIXURS, Tuticorin , Prasmo Agri Pvt. Ltd, Kumbakonam are involved in cultivation and purchasing of this seaweed through buyback arrangement with SHG's. Nearly more than 1000 fishers are involved in seaweed farming.

Open and bag cultivation methods

The polythene bags with the size of 45x45 cm were used for the experiments. 30 meter length of 8mm thickness polypropylene ropes were used for the open cultivation. Young and healthy plants of Eucheuma weight an initial weight of 100 is seed material. During the first 60 days, no significant difference in increase of biomass over the initial weight and of average DGR was observed between the bag culture (5.1%) and the open culture (5.3%) methods. However, later, increase in biomass and DGR were higher in open culture (3.2%) than in bag culture (1.3%) over the next 30 days. In open culture, increase in biomass was 1.9% more than in bag culture. Plants grown in bags were comparatively thinner (3-8 mm diameter), much branched and smooth in texture (Figure 1a), whereas in open culture, plants appeared robust, thicker (5-13 cm diameter) and with many broken lateral branches and wart-like lateral appendages. Although no significant difference was observed in carrageenan yield (ca 49%) between the two methods of cultivation, comparatively high gel strength of carrageenan was obtained from open culture method (250 g cm^{-1}).

Raft cultivation of *Kappaphycus alvarezii*

Hallo bamboo (3x3 m) was used for raft preparation; all the rafts were made with diagonal bamboo support. The depth of the sea where the rafts were placed is 0.5-1.0 m, all the rafts are within 50m from the shores. Plants near to the bamboo are giving more biomass than other plants (about 1.0% more). Similarly ropes which are very straight (without any 'bow' effect) giving more growth. 3mm thickness ropes were used for plantation.

Preparation of raft Preparation of Seedling ropeTying the seedling ropes in the raft

Kappaphycus raft ready for harvestHarvestingReseeding and placing back

Fig .1 various steps involved in bamboo raft cultivation of *Kappaphycus alvarezii*

1. Economics of *Kappaphycus* cultivation

Table. 1.INFRASTRUCTURE INVESTMENT - RAFT COSTING*

Sr. No.	Particulars/Specifications	Quantity	Rate (□)	Cost/ Raft (□)
1	3-4” dia Bamboos of 12ft×4 for main frame + 4ft×4 for diagonals	64 feet	4.50/feet	288
2	Five-Toothed Iron Anchor of 30 kg each (@□ 35 per kg) – two anchor can hold a cluster of 10 rafts	1.5kg	80/kg	120
3	3mm PP twisted rope for plantation – 20 bits of 4.5m each	0.45kg	150/kg	67.5
4	Cost of HDPE braider pieces (20 pcs × 20 ropes = 400 pcs of 25cm each)	0.150kg	210/kg	31.5
5	Braider twining charges @ □ 4.0/20 ties. For one raft 400 ties = □ 80	20 ropes	4/rope	80
6	Raft framing rope 6mx12 ties per raft i.e. 36mts of 6mm rope	0.65kg	150/kg	97.5
7	HDPE Used Fishing Net to protect the raft bottom (4m×4m size) + labour charges □ 10	1.0 kg	100/kg	100
8	2mm rope to tie the HDPE net (28mts)	0.09kg	160/kg	14.4
9	Anchoring rope of 10mm thickness (17m per cluster of 10 rafts)	0.09kg	150/kg	13.5
10	Rafts linking ropes per cluster 10 rafts – 6mm thick – 2 ties × 3m × 9pairs = 54m length	0.1kg	150/kg	15
11	Local transport infrastructure			120
12	Seed material 150 × 400 ties + 5kg handling loss = 65kg	65kg	3/kg	195
13	Raft laying + maintenance cost	-	-	150
14	Total raft cost			1292.4
	Total cost per raft (rounded off)			**1300**

* The costing might vary according to the prevailing market rate.

Economics of individual farmer through fresh seaweed sale

Model: Floating Bamboo raft

Table. 2 A) Cultivation Operation

Sr. No.	Descriptions	
1	Total no. of rafts	45
2	Harvest cycle (period)	45
3	No. of raft(s) handling per day	1
4	Total seaweed after harvest from 1 raft (kg)	200-250
5	Total seed required for re-plantation for 1 raft @ 60 kg (Kg)	40
6	Net produce from 1 raft after deducting seed / day	200
7	Fresh-weed produce (kg) available in a month (200 × 25 days operation)	**5000**

Table .2 B) Economics – FRESH SEAWEED

Sr. No.	Descriptions	□
1	Cost of one kg fresh-weed	3.0
2	Gross monthly income (5000kg × 3.0)	15000
3	Loan repayment – monthly EMI	1000
4	Net monthly income	**14000**

Economics of individual farmer through dry seaweed sale

Model: Floating Bamboo raft

Table .3 A) Cultivation Operation

S.No.	Descriptions	□
1	Total no. of rafts	45
2	Harvest cycle (period)	45
3	No. of raft(s) handling per day	1
4	Total seaweed after harvest from 1 raft (kg)	200-250
5	Total seed required for re-plantation for 1 raft @ 60 kg (Kg)	40
6	Net produce from 1 raft after deducting seed / day	200
7	Dry weed available from 200kg fresh weed (10:1 dry ratio) (Kg)	20
8	Dry produce available in a month (20 × 25 days operation) (Kg)	500

Table .3 B) Economics – DRY-WEED

Sr. No.	Descriptions	□
1	Cost of one kg Dr-weed	22.0
2	Gross monthly income (500kg × 22.0)	11000
3	Loan repayment – monthly EMI	1000
4	Net monthly income	**10000**

Other drift algae and wastes (plastic bottles etc.) are accumulated in the raft and it needs to be cleaned on daily basis (pulling down the raft into water for minutes and wastes & other algae will automatically be flown with water motion). *Entromorpha, Hypnea* and other algae (from spores?) are grow well on the bamboo poles and along with Eucheuma

Light tip and pigment picking grazing is seen in the raft whereas it is more in the raft, which are not covered with old fish net (basket effect) below the ropes.Raft grown plants are with ‘flower’ texture & mono line grown is typical ‘tambalang’ Plants are generally greenish brown in color. No grazing. New tips have developed like ‘centipede. Therefore, it is expected that using this raft grown plants as seeds will improve the yield in second generation Grazers in some times get into raft by jumping and generally they get trapped and die. No grazing is seen from these jumping fishes. The raft method yielded higher biomass than polythene bag.

The farming of *Kappaphycus* adopted raft and mono line system has evolved in conjugation with innovations in biomass processing. The bio-economic analysis for individual and artisanal culture of *K. alvarezii* in India reported a positive, net -present value 6-month after inception of the business, with an internal rate of return at 210% (Jara and Riffo, 2015). This analysis further endorsed the added benefits that *K. alvarezii* farming could the diversification of coastal livelihoods where opportunities are limited. The socio-economic impact of *K. alvarezii* farming in India has been investigated in depth as a part of the study sponsored by FAO (Krishnan and Narayanakumar, 2010).This study reveal that India has been able to circumvent most of the problems that seem to be haunting the development of seaweed sector in other developing countries. The adoption of the SHG model in seaweed culture in India by PepsiCo from 2003 has proved to be a big success. Participatory approach in culture and management via contract farming has enabled rapid expansion of this activity that began as a livelihood option and is now developing into an organised and institutionalized socio-economic transformation of these farming villages in India. Figure 1 reveal the biomass production of *Kappaphycus* and its value in India in last one decade. In the past seven years the *Kappaphycus* production was gradually increased and maximum of 1490 metric tons dry weed have been produced in 2013. There was a mass mortality occurred in September, 2013 due to ice-ice” disease leads a heavy loss in biomass production, however, now the growth and biomass production is steadily increased (Vaibhav et al 2017)

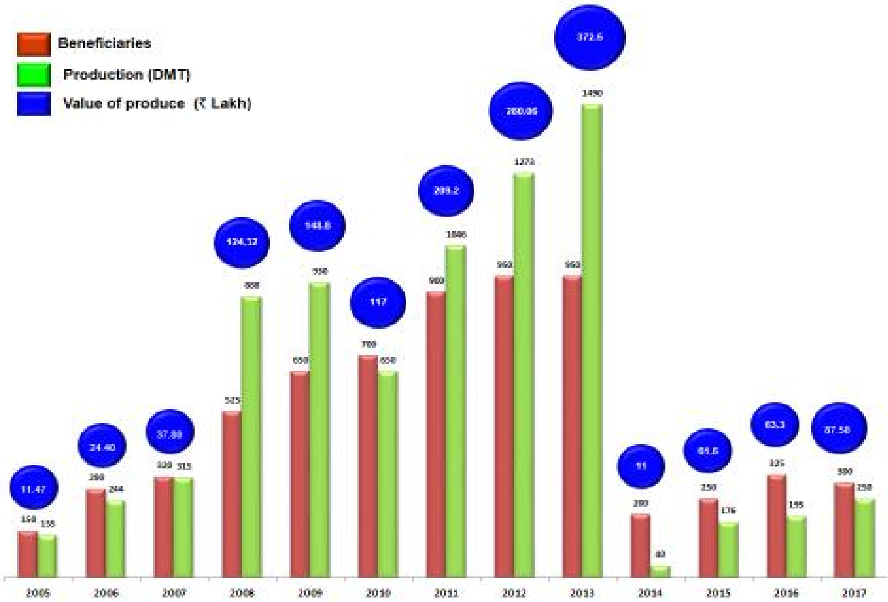


Fig. 2. Data on growth of *Kappaphycus* farming in India.

Kappaphycus alvarezii is one of the valuable tropical red seaweeds, which contain polysaccharide, *kappa*-carrageenan (κ-carrageenan), of commercial importance. Seaweed polysaccharides, by virtue of their unique gelling properties are used as an emulsifier, binder, thickener and gelling agent in diverse bulk products such as toothpaste, cosmetics, ice cream, pet foods, beverages, pharmaceuticals, personal care and dairy products. As a result this reason only, this seaweed is farmed commercially in a number of Indo-Pacific Ocean countries since the raw material supplies of natural stocks, fall far below that can supply the demand. Among the phycocollid yielding seaweeds harvested during 2010, carrageenophytes ranked top at about. About 5.6 million wt. was harvested with a corresponding farm gate value of US$ 1.4 billion (FAO, 2013). The Philippines, Indonesia and Malaysia are the major producers of carrageenophytes in the world, although Tanzania and several other countries have recently increased the production. India has recently registered an annual production of 2000 tons dry weight per annum.

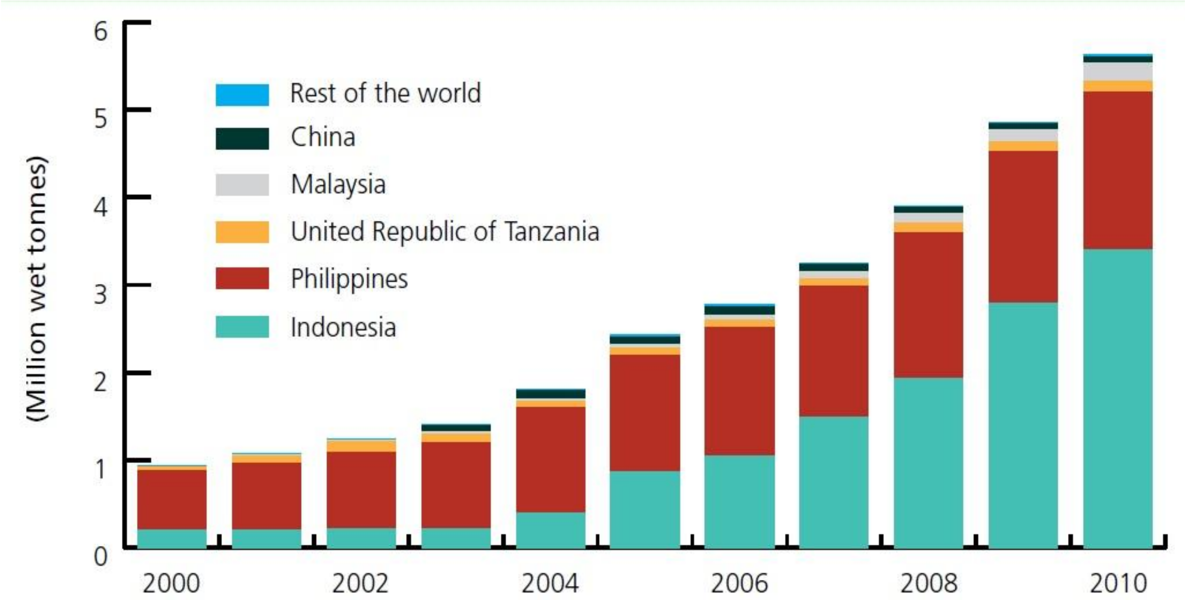


Fig . 3 World carrageenan farming production (Source FAO, 2013)

Year 2000			Year 2010		
Top 5 producers	**Quantity (1000 wet tons)**	**Share (%)**	**Top 5 producers**	**Quantity (1000 wet tons)**	**Share (%)**
World	**944**	**100.0**	**World**	**5,623**	**100.0**
Philippines	679	71.9	Indonesia	3,399	60.5
Indonesia	197	20.9	Philippines	1,795	31.9
United Republic of Tanzania	51	5.4	Malaysia	208	3.7
Kiribati	11	1.2	United Republic of Tanzania	132	2.3
Fiji	5	0.6	China	64	1.1
Top 5 total	**943**	**99.9**	**Top 5 total**	**5,599**	**99.6**

Table :4 Shift in production statistic

CSIR-CSMCRI, a constituent laboratory of Council of Scientific and Industrial Research (CSIR), New Delhi, Ministry of Science and Technology, Govt. of India has contributed immensely to the advancement of marine algal research in the country through its relentless research efforts. The R&D work carried out over many years resulted in development of various processes with potential commercial value. Many of these processes were granted patents and also formed the base for many seaweed industries currently operating within India. The *Kappaphycus* cultivation technology transferred to M/s. PepsiCo India Holdings Ltd in the early 2000s, ushered in the commercial farming of seaweeds, for the first time. At present, there are more than 1500 Self Help Group (SHG) members actively engaged in the commercial farming of *Kappaphycus* in Tamilnadu, earning an average monthly income of approximately Rs.7000/-. In 2011, the production of *Kappaphycus* was more than 20,000 tons on a fresh weight basis.

Seaweed cultivation has unique advantages such as it requires no land, no fresh water, no fertilizer, nor pesticide. Nevertheless, there are many challenges such as risk mitigation during calamities (cyclones), grazing by herbivores, and complexity of preserving the necessary germplasm during natural lean periods (e.g. monsoon time), for which effective solutions are yet to be developed.

CSIR-CSMCRI obtained a 10 g fresh sample of *K.alvarezii* from Japan in 1984 observing all necessary protocols and acclimatized the material to the Indian waters, first in Okha and subsequently in Mandapam, Tamilnadu. Beginning with a bag cultivation technology which was patented, it went on to demonstrate hectare scale cultivation of the seaweed (both monoline and raft cultivation), under a project funded by the Department of Biotechnology (DBT), the Govt. of India and with M/s. PepsiCo India Holdings Ltd as an industry partner. The partnering company subsequently licensed the know-how from CSIR-CSMCRI and first began the commercial farming of seaweed in India. The subsequent developments led to the concept of contract farming through SHGs with a buy-back guarantee. The cultivation of *Kappaphycus* is now viewed as a promising option for improving the socio-economic status of low income communities dwelling in the coastal regions of the country.

Although the initial interest in the red seaweed was for its κ-carrageenan, CSIR-CSMCRI invented a unique process (US Patent No 6,893,479; Indian Patent No. 224,938) to liquefying the fresh seaweed and derive two products, in an integrated manner, one being a granular residue rich in κ-carrageenan and the other being seaweed derived sap rich in potash and micronutrients with proven efficacy. Field trials of sap as a foliar spray in a variety of crops such as sugarcane, paddy rice, wheat, maize, potato, pulses and several fruits and vegetables has shown an improved growth and yields, e.g. 15 -40%, in different geographical locations across India.This technology – which was initially licensed to M/s PepsiCo, has now been commercialized by M/s. Aquagri Processing Pvt. Ltd. The licensee has built seaweed biomass processing plants for sap and carrageenan in Manamadurai (Sivaganga District), Tamilnadu. The sap is now being marketed in a formulated form in both domestic and overseas markets, while the carrageenan is supplied to both overseas and domestic industries.

The subsequent work on *Kappaphycus* led to the invention of several new products (also patented), with potential commercial value. The carrageenan which is extracted from the residue has been used as an ingredient in developing biodegradable films as a substitute for animal gelatin or carboxy methyl celluloses.*Kappaphycus* has the propensity to accumulate remarkably high amounts of KCl selectively from seawater and it is naturally extruded, partly (5-7% on dry wt. basis) especially during drying of the fresh seaweed. The residual salt as obtained from thrashing the dry seaweed is essentially muriate of potash (MOP). The MOP was utilized by CSIR-CSMCRI in the formulation of low-sodium salt, of plant origin.In another invention whereas the granules obtained as a by-product of sap preparation, which are a rich source of polysaccharides and it is used as a feedstock for bioethanol production. There is also scope for utilising the granules directly as a feedstock for thermal combustion in a gasifier to generate energy, the charred residue a rich source of potash, for soil application in agriculture. In the most recent development, the sap produced from the liquefaction of *Kappaphycus*has been processed to anutritious, tasty and affordable drink very similar to coconut water in taste. These multiple technologies have collectively contributed to make the

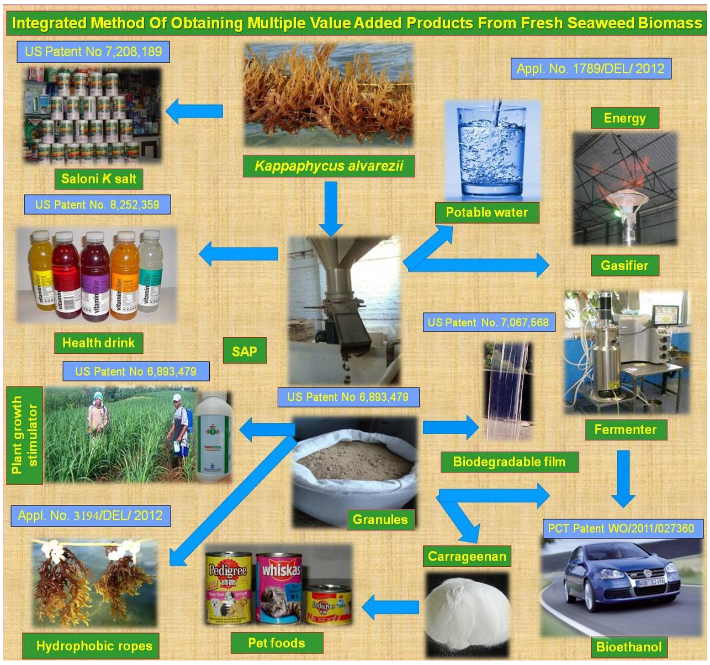


Fig : 4. Integrated process producing multiple products from *Kappaphycus*

Sr. No	Patent No.		Patent Title
1	US Patent No. 6,858,430 Indian Patent No.225,394	:	An improved process for cultivation of algae
2	US Patent No 6,893,479 Indian Patent No.224,938	:	Integrated method for production of carrageenan and liquid fertilizer from fresh seaweeds
3	US Patent No. 7,208,189 Indian Patent Appl. No. 2933/DEL/2005	:	Low sodium salt of botanic origin
4	US Patent No. 7,067,568 Indian Patent Appl. No. 1280/DEL/2005	:	Process of preparation of biodegradable films from semi refined kappa-carrageenan
5	PCT Publ. No. WO 2011/027360 A1 Indian Patent App. No.1839/DEL/2009	:	A process for integral production of ethanol and seaweed sap from *Kappaphycus alvarezii*.

6	US Patent No. 8,252,359	:	Method for the preparation of refreshing drink and use thereof
7	Provisional Patent Appl. No. 1789/DEL/ 2012	:	Process for improved seaweed biomass conversion for fuel intermediates and fertilizer
8	Provisional Patent Appl. No. 3194/DE/ 2012	:	Preparation of multifunctional hydrophobic ropes from kappa carrageenan
9	Provisional Patent Appl. No. 1078/DEL/ 2013	:	*Kappaphycus alvarezii* sap free of gibberellic acid (GA_3) and its method of preparation

Table : 5 The CSIR-CSMCRI patents pertaining to *K.alvarezii*

cultivation of *Kappaphycus* a new attractive option for income generation. In view of the gaining popularity of *Kappaphycus*seaweed cultivation, several maritime state government agencies have shown interest in promoting seaweed cultivation as a potential alternative livelihood for socio-economic empowerment of low income coastal communities. It is in this context, we realized the need for preparation of a seaweed cultivation manual, describing the best practices of *Kappaphycus*cultivation, which will not only help capacity building of stakeholders but also constitute guidelines aimed at improving the quality of overall cultivation practices in order to achieve greater efficiencies and productivity.

Objectives of manual preparation

The main purpose of this manual is to familiarize existing and prospective farmers with the proper and the best method of farming the *Kappaphycus*. The manual briefly deals with the following aspects

- Site selection
- Methods of cultivation, including seedling preparation and transplantation
- Farm management
- Harvesting
- Post-harvest storage
- Cost benefit analysis

2. Selection of the site

The farm is located ideally below the low water level, where about 2 ft. of water remains, even during the lowest of low tides. The water movement in the area should be moderate enough such that it would provide flow of fresh nutrients, essential to achieve continuous seaweed growth. The bottom of the site is preferably sandy, without any other seaweeds and/or seagrass beds. Suitability of site can only be confirmed through trial cultivation. The physic-chemical properties of seawater required for selection of suitable sites for farming of *Kappaphycus* are detailed below:

Sr. No	Parameter		Range
1.	Atmospheric Temperature (^{o}C)	:	26-35
2.	Seawater Temperature (^{o}C)	:	24-31
3.	Salinity (ppt)	:	24-35

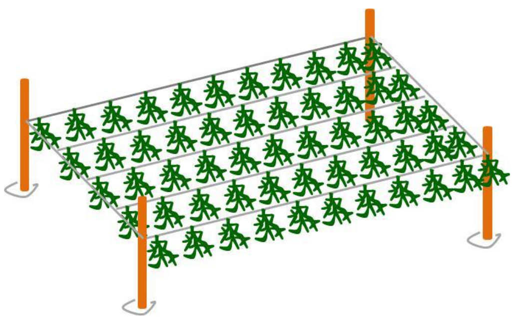
4.	pH	:	7.9 -8.5
5.	Dissolved oxygen (mg/lit)	:	2.0-3.5
6.	NO_2 (µg/lit)	:	0.14 -1.0
7.	NO_3 (µg/lit)	:	1.2 -3.0
8.	PO_4(µg/lit)	:	0.5-3.0

Table : 6 Optimum parameters need for seaweed cultivation

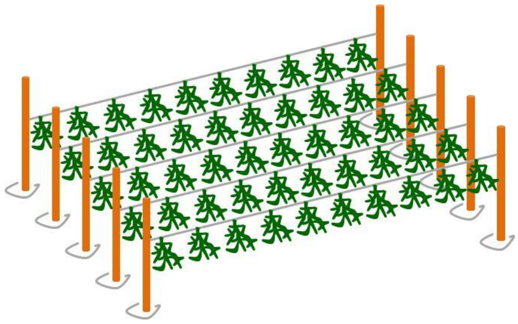
3. Methods of cultivation of the red seaweed *Kappaphycus*

In the sea, seaweeds are generally found growing attached to rocky substrata in the intertidal and shallow sub-tidal waters, where light penetrates. The nutrients required for the growth of seaweed are present in the seawater itself. It is therefore crucial to have currents which continuously flush the site, where seaweed beds exist. Harvesting of seaweeds from the natural beds is unsustainable, for commercial utilisation and hence related species are farmed in the sea in a most cost effective manner. The farming of seaweeds not only mitigates the pressure on natural beds, but also allows for selection of strains with desired traits. Seaweed farming is now gaining prominence in many countries because of their utilisation in agriculture and bioenergy sectors, in addition to traditional uses as food and phycocolloids.

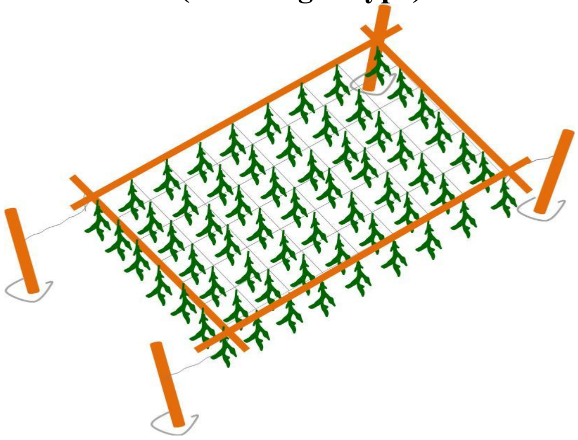
There are several methods, practiced world-wide, for the extensive cultivation of *Kappaphycus*. The diagrammatic representations of the most common methods are illustrated below. However, the bamboo raft method is widely followed in India, and a detailed step by step description is provided for the benefit of farmers.



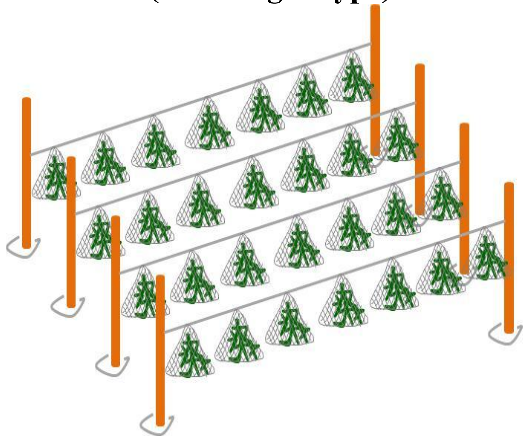
Net and stakes method (Submerged type)



Monoline method (Submerged type)



Bamboo raft method (Floating type)



Net bag method (Submerged type)

Fig : 5 Diagrammatic View of different method of ult8ivaion

a) *Bamboo raft method*: Although *Kappaphycus* can be cultivated following different methods, the bamboo raft method has been found to be the most simple, cost-effective and user friendly method for Indian waters. Materials required for the bamboo raft method are given under:

Sr. No	Item name and description
1	12 feet long bamboo Poles (3-4″ dia.)
2	4 feet long bamboo Poles (3-4″ dia.)
3	Polypropylene seeding rope (3.5 mm dia.)
4	Tie-Tie rope (1 mm dia.)
5	Polypropylene Anchor rope (12-16 mm dia.)
6	Weighing scale : 0-1 kg; 0-20 kg
7	Measurement Tape
8	Thermometer (10-50ºC)
9	Refractometer
10	Anchor (30 kg wt.)
11	Motorized or manual saw
12	Fish net to cover the lower side of raft
13	Algal seed material

Table : 7 Required items for bamboo raft cultivation

Fig : 6 Material required for fabrication and transplantation of the bamboo raft in the sea

Fig : 7 Fabrication of bamboo raft

Fig : 8 Pile of fabricated bamboo rafts

The bamboo floating rafts of various sizes can be used according to the cultivation site.

- A raft made up of bamboos of 3-4″ in diameter and 12′ × 12′ in size is used for fabrication of the main frame used for cultivation.
- The angular portions are diagonally fixed with the help of supporting bamboos of 4′ length in order to keep the raft structure intact.
- The polypropylene seeding rope (3.5 mm dia.) is cut into 3.5 m length for planting of seedlings.
- The tie-tie rope (1 mm dia.) is cut into 15 cm length and prepared a loop with a fixed knot.
- The loops are then inserted between the braider of the seeding rope at 15 cm intervals and fixed with a knot. Each seeding rope will have a total 20 tie-tie loops.
- Selected seedlings of approximately 100 g fresh weight each were inserted into the loop and held firmly without breakage.
- The seeding ropes thus seeded are tied across the raft in parallel to one other at 15 cm intervals.
- Total 20 plantings are made on each rope, at 15 cm intervals, accounting to an initial weight of 2 kg seedlings per rope.
- One raft with 20 such ropes has an initial seedling weight of 40 kg fresh weight (2 × 20) per raft.
- Lower side of the raft below the rope is covered with fish net (1 mm diameter, 1cm mesh size) to minimize grazing as well drifting of plant material.
- The rafts, in a cluster of 10, are placed in the sea with an anchor stone (approx. 30 kg), at both ends, to ensure buoyancy, stability as well as protection from drifting from wave action.

Fig : 9 Insertion of loops between braiders of seeding rope

Fig : 10 Seeding of planting ropes with algal seed material

Fig : 11 Tying of seeded rops to the bamboo rafts

Fig : 12 Women SHGs with fully seeded bamboo raft being transplanted in the sea

Fig : 13 Farmer cleaning the floated rafts in the sea

Fig : 14 Bamboo raft with fully grown *Kappaphycus* crop after 45 days

b) *Tube-net method of cultivation*: This method is in every respect similar to that of bamboo raft method except for a change in the seeding practice. In this method, there would also be fabrication of a bamboo raft, preparation of 20 seeding lines, of 3 m length each with 2 kg seed material. In this method the seed material is not fastened with tie-ties but held compactly, inside tube- nets having 10-15 cm dia. and mesh size of 3 cm. The algal seed material is loaded into the tube-nets with the aid of a small plastic pipe having little less dia. than tube-net.

- A raft made up of bamboo of 3-4″ in diameter and 12′ × 12′ in size is used for fabrication of main frame for tube-net method of cultivation.
- The angular portions are diagonally fixed with the help of supporting bamboo of 4′ long in order to keep the raft structure intact.
- 10-15 cm dia. plastic tube-net having 3-4 cm mesh size was cut into 3 m length.
- The tube-nets are filled with seed materials (2 kg fresh wt.) with the aid of a plastic pipe with somewhat less dia. than the plastic tube net.
- The plastic tube-nets thus made are loaded with seed materials and tied in parallel in equidistantto each other, across the raft, similar to the earlier method.
- Total of 20 tube-nets, each having an initial seed weight of 2 kg, is tied to each raft.
- One raft, with 20 tube-nets will has an initial seedling weight of 40 kg fresh weight (2 × 20) per raft.

- The rafts, in clusters of 10, are placed in the sea with an anchor stone (approx. 30 kg), at both ends, to ensure its buoyancy and stability, as well as protection from drifting from the wave action.

Fig : 15 Cutting of fish net for making tube nets

Fig : 16 Making of typical tube net

ig : 17 Women SHG members sealing of tube nets with algal seed material

Fig : 18 Tube nets with algal seed material ready for tying on bamboo rafts

Fig : 19 Women members with seeded bamboo raft ready for transplantation to the sea

Fig : 20 Transplanted bamboo rafts in the sea

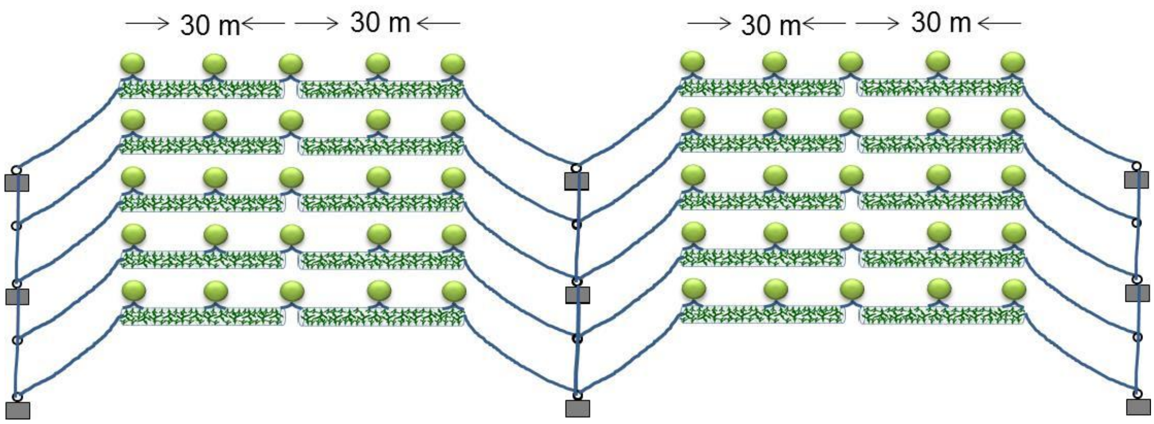
Fig : 21   45 days old bamboo rafts, with fully grown algal crop, ready for harvest

Fig : 22 Close-up view of a single tube net with fully grown algal crop, after 45 days growth

Fig : 23 Farmers carrying the algal crop

In ideal conditions as stated above, it is possible to harvest a biomass of 200 – 250 kg fresh wt., from each raft. Of this, about 40-50kg is to be utilised as seed for subsequent farming cycle. Each person needs to seed one raft, in a day, and this will cycle grow out after 45 days, thereafter he will have to harvest one raft (that has been planted on the day one) and re-seed the same raft, besides attending to the regular farm maintenance activity. Thus this cycle continues after 45 days. About 6-7 cycles can be undertaken during one year depending on the season and farm location.

c). *Tube-netmonolinemethod*: The prevailing sea conditions in the farm would determine the most appropriate method to be adopted for *Kappaphycus* cultivation. The tube-net method has been found to be very promising for farms where wave action is more than moderate. The higher wave action may cause frequent loss of germlings in early growth phase or loss of crop before of harvest. For farming in such locations, the tube-net method has been found to be a secure method of cultivation of *Kappaphycus*. The tube-nets (15 cm dia; mesh size of 2.0 cm) of 30 m length, are used. Each tube-net is held floating in the water column below the surface with appropriates size floats at regular intervals as shown in the figure below. Anchors stones (about 30 kg) are used at each end to hold the tube- nets steadily in the water column. The seed material of 20 kg fresh wt, is loaded into the tube-nets with the aid of a 1.0 or 1.5 m length plastic pipe acting as a funnel or a hopper. The plastic pipe dia. is either same or little less than that of tube-net. First the plastic pipe is inserted into the tube-net and the entire tube-net pulled down, so that way that the mouth of plastic pipe stands out of the tube-net. The seed material intended for the tube-net is first filled in the plastic pipe. The tube-net is pulled down from the bottom of the plastic pipe carefully, in such a way that seedling material gets loaded into the tube-net. This process is continued till the entire tube-net is filled with seed. Then the tube-nets are closed at both ends with cable ties to prevent material being lost.



The tube-nets filled with seed material are finally transplanted, in rows and held firmly with the help of anchor supports and floats. The tube-nets thus suspended in the sea are prone to epiphytic growth in the initial stages especially during summer months. It is very crucial that the farmers closely monitors of the suspended tube-nets for their first three weeks for epiphytic growth and sea drifts that may be detrimental to the farming activity. The harvesting cycle of tube-net method is also the same as that of raft method.

4. Production statistics:

The seaweed farming production in India has been increased from over 20 tons dry weight to about 1800 dry tons recently. The harvested seaweeds are dried and then bundled into bales. There are some areas where platforms have been created to facilitate drying but most of the farmers still prefer to dry the biomass on open shore sands. Although most of the biomass has been exported initially this trend is now reversed, due to discovery of innovative method of obtaining two value added products from the fresh biomass. The large preparation of fresh biomass goes into production of liquid seaweed sap (rich in hormones and trace elements) while the residue is being used for production of semi-refined carrageen.

Table : 8. Year wise biomass production of *Kappaphycus* seaweed in Indian waters

Year	Total farming area (raft no)	Beneficiaries	Dry-weed Production (MT)	Purchase price (□/ kg)
2001	Trial	6	21	Trial
2002	5275	6	82	Trial
2003	5529	12	147	4.5
2004	3469	40	126	7.5
2005	3450	150	135	8.5
2006	8100	280	244	10
2007	9500	320	315	12
2008	12000	525	888	14
2009	14000	650	930	16
2010	16000	700	650	18
2011	17000	900	1046	20

2012	19950	950	1273	22
2013	21000	950	1490	25
2014	450	200	40	27.5
2015	21000	1100	1800	35

Data courtesy: M/s. Aquagri Processing Pvt. Ltd.

The flowing table shall provide information onproduct yield and their market value realizable from downstream processing of one ton biomass fresh.

Table : 9 Product yield and market value

Products	Product quantity	Market price (□)	Total amount (□)
Liquid sap	600 liters	70 /Lit	42,000/-
Semi refined carrageenan (SRC)	30Kg	450/kg	13,500/-
Total combined value of these products			55,500/-*

*Exclusive of capital investment and processing cost

5.Farm management

The productivity of a*Kappaphycus* farm depends on the management practices adopted by cultivator. The motivated farmers always excel in farming and realize the highest returns. The rafts transplanted in the sea are likely to have infestations with undesired floating materials, drifted from different, which have unknown sources. Continued presence of such infested materials on rafts seriously compromises the growth and productivity of the *Kappaphycus* seaweed farms. Occasionally, undesired algal growth also takes place on the rafts and hinders the growth of the farmed seaweed. In order to achieve optimal production volumes, the cultivator has to visit the farm frequently, and undertake periodic cleaning of rafts and weeding of any foreign materials. The rafts also get damaged occasionally, due to high wave action. The damaged rafts must be repaired to obtain satisfactory crop yields. It is very important that the farmer keeps closely monitoring his farm and initiates appropriate measures to avert slow growth, or even total loss of the crop. Many of the above problems are seasonal. Frequent human movement in the farm also keep grazers (herbivorous fish and molluscs) out of the farming locations.

Fig : 24 Cultivator cleaning the floated rafts in the sea

6. Harvesting

The seedlings grown for 40-45 days attains their full growth with 100% cover of the rafts. These rafts ready to harvest are towed ashore and the ropes are detached from raft and brought to the beach where the materials are pulled out from the loops manually. The harvested crop is solar dried on platforms, erected for drying purpose or dried on plastic sheets on beach. Direct drying of plants on beach sand is discouraged as the crop might have sand mix. Drying of material may take 5-6 days period depending on sunshine hours. In Tamilnadu, the fresh crop itself is procured by buyer and used for sap production in the factory.

In the case of the tube-net system, the external growth protruding from the tube-nets can be pruned by hand cutting or can be employed a special mechanical device similar to hand cutting. The material trapped inside the tube nets can be processed directly for sap extraction while the pruned material can be used as a seed stock for subsequent farming purposes. The tube-nets after pruning can also be put back in for cultivation for a second crop cycle. However, the farmer has to monitor the yields obtained from successive harvests being made from the tube-nets. If the crop yield declines, it is recommended to replenish the tube nets with a fresh stock of seed material, to achieve sustainable yields.

Fig : 25 Heap of harvested algal crop from rafts

Fig : 26 Pruning of algal crop

7.Post-harveststorage

The dried material, with about 35% moisture content, is compressed and packed in either jute or plastic sacks. If the material was dried directly on the beach sand, the dried material as shown below is cleaned on mesh platform to remove the adhering sand content. It is advisable that the dry crop is sold alone as soon as possible, as prolonged storage may cause deterioration of the quality of crop, resulting into lower remuneration to the farmer.

Fig : 27 Cleaning of dry biomass

Fig : 28 Storage of dry biomass in gunny sacks

8. Germplasm preservation during natural lean periods

Seaweed cultivation is a seasonal activity on the Indian coast. The sea during the monsoon period (i.e. June-September) is very turbulent and poses severe challenges for continued seaweed farming activities. During the monsoon period, farmers are advised to reduce the farming activity and preserve the germplasm in tube-nets, in sheltered areas, or shallow bays with moderate wave action. Alternatively, we would also like to advocate the construction of large shallow ponds, or tanks, in the intertidal zone which could be used for storage of bulk volumes of *Kappaphycus* during monsoon period. These tanks could be covered with plastic mesh to prevent drift of material during the high tide period. On a most recent visit to Gadula Village in Talaja Taluka (Bhavnagar District), we have come across of such tanks, which were constructed by the State Fisheries Department for crab culture. The suitability of these ponds for germplasm storage, during the lean period is being explored, in addition to farming in sheltered areas and bays.

9. Economics of *Kappaphycus* cultivation

Table. 10. INFRASTRUCTURE INVESTMENT - RAFT COSTING*

Sr. No.	Particulars/Specifications	Quantity	Rate (□)	Cost/ Raft (□)
1	3-4” dia Bamboos of 12ft×4 for main frame + 4ft×4 for diagonals	64 feet	4.50/feet	288
2	Five-Toothed Iron Anchor of 30 kg each (@□ 35 per kg) – two anchor can hold a cluster of 10 rafts	1.5kg	80/kg	120
3	3mm PP twisted rope for plantation – 20 bits of 4.5m each	0.45kg	150/kg	67.5
4	Cost of HDPE braider pieces (20 pcs × 20 ropes = 400 pcs of 25cm each)	0.150kg	210/kg	31.5
5	Braider twining charges @ □ 4.0/20 ties. For one raft 400 ties = □ 80	20 ropes	4/rope	80
6	Raft framing rope 6mx12 ties per raft i.e. 36mts of 6mm rope	0.65kg	150/kg	97.5
7	HDPE Used Fishing Net to protect the raft bottom (4m×4m size) + labour charges □ 10	1.0 kg	100/kg	100
8	2mm rope to tie the HDPE net (28mts)	0.09kg	160/kg	14.4
9	Anchoring rope of 10mm thickness (17m per cluster of 10 rafts)	0.09kg	150/kg	13.5
10	Rafts linking ropes per cluster 10 rafts – 6mm thick – 2 ties × 3m × 9pairs = 54m length	0.1kg	150/kg	15
11	Local transport infrastructure			120
12	Seed material 150 × 400 ties + 5kg handling loss = 65kg	65kg	3/kg	195
13	Raft laying + maintenance cost	-	-	150
14	Total raft cost			1292.4
	Total cost per raft (rounded off)			**1300**

* The costing might vary according to the prevailing market rate.

Economics of individual farmer through fresh seaweed sale

Model: Floating Bamboo raft

Table : 11 A)Cultivation Operation

Sr. No.	Descriptions	
1	Total no. of rafts	45
2	Harvest cycle (period)	45
3	No. of raft(s) handling per day	1
4	Total seaweed after harvest from 1 raft (kg)	200-250
5	Total seed required for re-plantation for 1 raft @ 60 kg (Kg)	40
6	Net produce from 1 raft after deducting seed / day	200
7	Fresh-weed produce (kg) available in a month (200 × 25 days operation)	**5000**

Table : 11 B Economics – FRESH SEAWEED

Sr. No.	Descriptions	□
1	Cost of one kg fresh-weed	3.75
2	Gross monthly income (5000kg × 3.75)	18750
3	Loan repayment – monthly EMI	1000
4	Net monthly income	**17750**

Economics of individual farmer through dry seaweed sale

Model: Floating Bamboo raft

Table : 12 A Cultivation Operation

S. no.	Descriptions	□
1	Total no. of rafts	45
2	Harvest cycle (period)	45
3	No. of raft(s) handling per day	1
4	Total seaweed after harvest from 1 raft (kg)	200-250
5	Total seed required for re-plantation for 1 raft @ 60 kg (Kg)	40
6	Net produce from 1 raft after deducting seed / day	200
7	Dry weed available from 200kg fresh weed (10:1 dry ratio) (Kg)	20
8	Dry produce available in a month (20 × 25 days operation) (Kg)	500

Table : 12 B Economics – DRY-WEED

Sr. No.	Descriptions	□
1	Cost of one kg Dry-weed	35.0
2	Gross monthly income (500kg × 3.0)	17500
3	Loan repayment – monthly EMI	1000
4	Net monthly income	**16500**

Caution notes

- The red seaweed *Kappaphycus* is strictly a marine form. The cultivation farm cannot be located in areas having the sources of fresh water inflow regularly.
- The rafts have to be transplanted in orderly manner leaving enough space between the rows for movement of fresh seawater. Crowed cultivation is detrimental to the growth and productivity of farming activity.
- The overcrowding of farm with rafts, poor seawater circulation causes nutrient depletion in the farm and exerts extreme stress on seaweed crop leading disease outbreak devastating the farms.
- Seaweed being a submerged form, it cannot endure prolonged desiccation. It is important that the seaweed is always kept in seawater or moistened condition with minimum desiccation exposure.
- The farming operations are carried out rapidly and no damage is caused to seaweed arising from prolonged exposure to desiccation and freshwater contact.
- The farmer has to have fair understanding of tidal height in the region where his farm is located. It is important to ensure that rafts in cluster do not colloid with neighbouring clusters.
- The seaweed has to be well managed to have sustainable crop yields. The epiphytes, grazers, sedimentation and damage of cultivation frames by tidal waves are of some important challenges to be addressed by farmer routinely.
- The harvested crop needs to be dried in a most specific manner in such that there would not be beach sand, shells and debris of cultivation and other seaweed material mixing with crop.
- The moisture content of dried crop should not be more than 35%. The dried crop with higher moisture content may lead to microbial contamination during storage leading to poor grade of crop and value.
- The beach, where the farming activities are carried out, is to be maintained litter free (free of algal refuse, plastic floats, debris from rafts etc.).