Chapter 7
Large Scale Algal Biomass (*Spirulina*) Production in India

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7.1 Introduction

large-scale farms around the world, using a wide range of algae production systems like *Spirulina* growing in natural lakes, commercial farms using outdoor raceway pond systems, photo bioreactors, integrated commercial production farms, village farms in the developing world with appropriate technology, micro farms, family and community size production systems. *Spirulina*, the spiral shaped microscopic aquatic plant, is the richest and the most complete nutrition discovered so far. These tiny green spiral coils harvest the energy of the sun, growing a treasure of bioavailable nutrients. *Spirulina* has the natural tendency to grow in alkaline water bodies, where growth of other algae and micro organisms is minimal. *Spirulina* cultures are almost monocultures and much less susceptible to contamination as compared to many other algal cultures.

In India, research and development on *Spirulina* production started by 1977. Even though, pilot capabilities were achieved in 1980, and further developmental works were delayed due to investor perception of *Spirulina* as a futuristic product. Commercial production was started in 1944 and at present there are many major producers of *Spirulina* in India. *Spirulina* is marketed in India mainly as formulated products like tablets and capsules by several pharmaceutical companies.

Millions of people worldwide eat *Spirulina* cultivated in scientifically designed algae farms. Current world production of *Spirulina* for human consumption is more than one thousand metric tonnes annually. The United States leads world production followed by Thailand, India and China (Henrikson, 1997). There are no apparent production data available about the quantity of *Spirulina* produced from India and the rest of the world; however, it was estimated that the world production was about

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3000 metric tonnes per annum in 2004 and now it may be close to about 7000 metric tonnes and from India it may be close to 1000 tonnes per annum in 2014 across large, medium and small *Spirulina* farms.

7.2 Large, Medium and Small Scale *Spirulina* Production

7.2.1 Industries Producing in Large Scale

Spirulina has been produced by industries on a large scale in raceway ponds adopting the mechanised agitation, filtering and drying systems with relatively higher capital investments. Their minimum capacity is about 10 tonnes per year and the biggest producer in India has the present capacity of about 300 metric tonnes a year (Fig. 7.1).

The best examples are the leading Murugappa group's Parry Nutraceuticals, Pudukkota; Dabur group's Sannat Products, Tamil Nadu; and NB Laboratories, Nagpur, Maharashtra. There are about ten such industries producing about 600 tonnes of *Spirulina* per annum The most parts of the large scale *Spirulina* production is being exported directly by the producers or indirectly by the traders as *Spirulina* powder or the value added products like capsules, tablets or flakes to Europe, North America and Australia.

7.2.2 Small and Medium Scale Spirulina *Production*

In medium and small scale, *Spirulina* production is carried out by the small entrepreneurs. The NGOs (Nongovernmental Organisations) and social institutions are using the manpower like SPRTC model. In this model the producers adopt different types of pond construction like the concrete tanks (square or rectangular), tanks made of tarpaulins and even multiple small tanks. This type of tank is mostly

Fig. 7.1 Large scale *Spirulina* production by Parry Neutraceuticals and SPRTC, Madurai.

manually operated; thus the daily harvest, pond agitation and drying (sun drying in most farms) are carried out by the farm workers.

Though this model is very attractive and less profitable, this type of *Spirulina* production is not capital intensive and offers the employment to the self help groups [SHGs] and encourages them to come forward to start their own *Spirulina* production units at remote villages. They are also now facilitated by the banks and NBFIs (non banking financial institutions) through micro-credit projects. There are many such running models established in the north and south Tamil Nadu and the women of the SHGs are able to increase their income considerably. The few examples are SPRTC-Madurai, CHDP-Nagarkoil, Aurospirul-Pondycherry, SURYA-Thindivanam, and WED-PMS-Madurai (http://www.antenna.ch/en/research/malnutrition/spirulina-Production).

7.2.3 Advantages of **Spirulina** *Local Production*

The local production of *Spirulina* gives communities access to a local and sustainable source. The cultivation of *Spirulina* has its humanitarian aspects because it brings with it a growing awareness by stakeholders of the causes of malnutrition and of its own role in enhancing the nutritional state of a country. By deciding to grow their own *Spirulina*, developing countries can gradually integrate it into eating patterns. This route will allow it to become not only an excellent weapon in the fight against malnutrition but also a real tool for development. The local communities are highly motivated to be involved in a commercial way. This can be done by establishing an efficient network for distribution and communication as well as a targeted education strategy with the local community on the nutritional qualities of *Spirulina*. There are considerable advantages of the small and medium scale *Spirulina* production over large scale production farms like: *Spirulina* is produced locally with the available facilities, the technology is simple, and not capital intensive (even with about USD 10,000 or INR 6,00,000 capital, the small *Spirulina* farm can produce about 1000 kg *Spirulina*).

7.2.4 Cost Estimation to Establish a Rural **Spirulina** *Farm with 400 m^2 of Production Area and Outreach*

7.2.4.1 A Model Rural *Spirulina* Farm and Outreach

Production size: About 400 m^2
Spirulina produced (Annual): 1000 kg a year (dry)
Employment possibility: 10–12 women (Production and promotion)
Possible reach of children: About 6000 children [Assuming 1 gm/child for 100 days]
Possible reach of adults: About 2000 adults [Assuming 3 gm per adult for 100 days]

This can also be used to reach about 12,000 children for 100 days with one gram *spirulina* a day.

Through this supplementation the malnutrition among children and women will substantially be reduced.

Note: There was a clinical experiment among children of 1–6 years of age with just one gram a day *Spirulina* supplementation for six weeks which had proven effects as in the study abstract as below (Table 7.1).

A clinical study abstract: *Spirulina* – A nutrition booster (Thinakar Vel et al., 1999)

STUDY SUPPORTED BY ANTENNA TECHNOLOGY, GENEVE AND ANTENNA TRUST, MADURAI.

SPIRULINA : A NUTRITION BOOSTER

Study by Mr.Thinakarvel, Prof. Dr. N.Edwin department of paediatrics Madurai Medical College and Government Rajaji Hospital, Madurai.

(Study paper Presented at the 7th World Congress on Clinical nutrition)

A GENERAL SUMMARY

- To study the nutritional benefits of Spirulina in a group of malnourished pre-school children (1-6yrs.) a total of 60 children were selected from ICDS block and Rajaji Government Hospital Madurai, of which 30 children were taken as test group and 30 were taken as control group
- The Study Period was for Six Weeks while the test group children were given Spirulina at a Dose of 1 gram per day. The control group children were given placebos.

The results are as follows:

PARAMETARS	TEST GROUP FED WITH SPIRULINA.	CONTROL GROUP NOT FED WITH SPIRULINA
	(% OF CHILDREN SHOWING IMPROVEMENT)	
Weight	63.33%	43.00%
Haemo globin	93.33%	23.33%
Serum Proteins	93.33%	16.66%
Serum total Iron	63.33%	40.00%
Serum Ferritin level	93.33%	16.66%
Serum retinol level	90.00%	26.6 %

The study duration of 6 weeks, assumes significance as the beneficial effects over a longer period will be greatly increased.

Apart from proteins Spirulina also gives Iron and Retinol. Thus Spirulina provides us with a cheap and widely available method of preventing nutritional deficiency amongst children in developing countries and helps them attain full growth and development potential.

Table 7.1 Expenditures involved in S*pirulina* cultivation

S. No	As on June 2014	INR	US$*
1	*Spirulina* cultivation training and seed culture cost	30,000	500
2	*Spirulina* cultivation tank construction and material cost	293,000	4883
3	Cost of production related accessories	32,120	535
4	Technical equipments cost	10,000	167
5	Cost of nutrients required for starting the culture	18,900	315
6	Cost for land preparation (leveling, fencing, water source, etc.)	90,000	1500
7	Technical support for one full year (12 months × INR 10000)	120,000	2000
	Total cost	594,020	9900

*For calculation 1 $ = 60 INR

7.3 Cultivation of *Spirulina*

In open *Spirulina* cultivation, the environmental suitability and the requirements are similar for the small, medium and large scale *Spirulina* farms even though the process differs. In order to cultivate *Spirulina*, one must provide all the necessary elements, in a situation which will permit the plant to absorb and utilize these elements. The situation involves a range of suitable temperature and illumination to provide the energy needed for photosynthesis, water and nutrients (Vonshak, 1997).

Normally *Spirulina* producing farms choose tropical region so that the required temperature range of 30–37 °C in day time and 25–30 °C in night time is obtained. Also rich source of water, 10 h of illumination (minimum), low humidity, low wind have to be ensured for good production. Regarding nutrient source requirement, one must provide organic/inorganic sources of carbon, nitrogen and minerals.

7.3.1 Tank Construction

Building *Spirulina* cultivation tank is very important since many parameters are to be considered in tank construction to ensure the efficient *Spirulina* culturing. Any water-tight, open container can be used to grow *Spirulina*, provided it will resist corrosion and be non-toxic. Its shape is immaterial, although sharp angles should be avoided to facilitate agitation and cleaning. *Spirulina* can be grown in tarpaulin (transferable) or permanent cement tanks. Most current commercial farms over the past 30 years have been designed with shallow raceway ponds circulated by paddle wheels. Ponds vary in size up to 5000 m^2 (about 1.25 acres) or larger, and water depth is typically 15 to 25 cm. They require more capital investment than lake farms, and operate at higher efficiency and quality control.

7.3.2 Culture Medium

Spirulina thrives in alkaline, brackish water. The culture medium provides all essentials to grow *Spirulina* in a suitable environment. It is composed of sodium carbonate, a source of nitrogen, phosphorus, iron and trace metals. The composition of growing medium is shown in Table 7.2.

In addition, the solution contains traces of all micronutrients necessary to support plant life. Such solution is obtained by dissolving various combinations of chemicals. Only food grade chemicals are used. The choice of chemicals and concentrations that are used depends on cost and the compatibility of the chemicals with the raw water. Cost of nutrients accounts for about 15–25% of the total production cost.

Table 7.2 Composition of the medium for the growth of *Spirulina*

Carbonate	2800 mg L^{-1}
Bicarbonate	720 mg L^{-1}
Nitrate	614 mg L^{-1}
Phosphate	80 mg L^{-1}
Sulphate	350 mg L^{-1}
Chloride	3030 mg L^{-1}
Sodium	4380 mg L^{-1}
Potassium	642 mg L^{-1}
Magnesium	10 mg L^{-1}
Calcium	10 mg L^{-1}
Iron	0.8 mg L^{-1}
Total dissolved solids	12,847 mg L^{-1}
Density @ 20 °C	1010 g L^{-1}
Alkalinity	0.105 N (moles strong base L^{-1})
pH @ 20 °C	10.4

7.3.3 Strain Selection

The major determinants in the selection of strains for commercial production are growth rate, biochemical composition and resistance to mechanical and physiological stress. A wide variety of species and strains of *Spirulina* have been screened by several people in various countries. Continuous mass production of a particular strain depends on its suitability and stability under prevailing conditions of the farm environment.

7.3.4 Scaling-up of the Process

The culture is scaled up from mother culture strains. The scale-up follows a roughly 5:1 dilution ratio through successive volumes up to the required culture in the production ponds. In the second mode of operation, culture expansion to the entire volume of a production pond can be done from seedling at the concentration of 1 g L^{-1}. The scaling up process is the stage in the process where contamination by other algae and bacteria poses the greatest problem because of the initial dilute nature of the *Spirulina* inoculum. There is a direct relationship between the density of *Spirulina* in the culture and the density of contaminants (Vonshak, 1997). Contamination by green algae is high when the initial density of the inoculum is low. Conversely, the amount of contamination decreases as the *Spirulina* culture builds up in density. It is speculated that extra cellular products of *Spirulina* may have some allelopathic properties. Threshold concentration of these substances is probably reached at high cell densities. Light limitation of green algae by the positively buoyant trichomes of *Spirulina* may also account for the observed phenomenon. Through careful manipulation of the nutrient concentration and useful natural predators, it has been possible to maintain a mono algal culture even during the initial period of inoculation.

7.4 Maintenance of Open Air Cultures

Proper culture maintenance calls for a routine monitoring of various physical, chemical and biological parameters as follows.

7.4.1 Effect of Light

Outdoor algal cultures are exposed to two rhythms of the dark and light regime. The first is relatively fast. It is induced by the mixing in the pond which results in a turbulent flow of the culture, dictating the frequency of the light cycle. In this cycle algae cells are shifted between full solar radiation when located at the upper culture surface and complete darkness when reaching the bottom of the culture, usually at a depth of 12–15 cm. The time scale of such a cycle is measured in fractions of a second. The other, relatively slower regime is the change in solar irradiance during the day from sun rise to sun set. These two light cycles impose a unique physiological regime on the adaptation or acclimatization of outdoor algal cells to light. When growing algae at a depth of 12–15 cm in open tanks, self-shading governs the light availability to the single cell in the culture (Vonshak, 1997). Unless one uses a much diluted culture which allows penetration of light throughout the water column, a certain part of the culture will always fail to receive enough light to saturate photosynthesis. Thus almost by definition this kind of culture will be light limited. Increasing the cell concentration of culture, this increases self-shading and results in decrease of the growth rate of *Spirulina*. An increase in productivity and highest production at a higher cell concentration are the results of increased turbulence flow by agitators.

7.4.2 pH Control

The pH of the medium is one of the most important factors in culturing *Spirulina*. Maintaining the pH over 9.0 is mandatory in *Spirulina* cultures in order to avoid contamination by other algae. pH adjustment is made by increasing carbon dioxide level by addition of carbonate salts in to the culture. The main areas of loss of CO_2 are exchange with the atmosphere, precipitation as $CaCO_3$ and loss to the part of the medium that is not recycled back to the ponds. It is rare that the pH of the medium falls below about 9.0 (once the medium is much diluted). However, increase in pH is quite common due to human error like improper/lack in addition of nutrients. When this occurs, it is accompanied by precipitation of $CaCO_3$, which is sometimes followed by flocculation and sedimentation of algae (Vonshak, 1997).

7.5 Harvesting, Drying and Packaging

The best time for harvesting is early morning for various reasons:

- The % proteins in the *Spirulina* is highest in the morning.
- The cool temperature makes the work easier.
- More sunshine hours will be available to dry the product.

The harvesting process involves two stages of filtration. In the first, filtration to obtain a "biomass" containing about 10 % w/v dry matter and 50 % w/v residual culture medium and removal of the residual culture medium to obtain the "fresh *Spirulina* biomass", ready to be consumed or dried and practically no residual culture medium.

Filtration is simply accomplished by passing the culture through a fine weave cloth, using gravity as the driving force. Synthetic fibre cloth with a mesh size of about 30 to 50 microns is the preferred filtering medium (Venkatraman, 1983). Supporting the filtration cloth by a fine net will accelerate somewhat the filtration and protect the cloth against rupturing. The filter can be installed above the pond to directly recycle the filtrate. The culture to be harvested should be passed through a sieve (mesh size about 200 μm) to remove any foreign matter such as insects, larvae, leaves and lumps of polysaccharide or mud.

The filtration is accelerated by gently moving or scraping the filter. When most of the water has filtered through, the biomass will often agglomerate into a "ball" under the motion, leaving the cloth clean (this desirable condition happens mostly when the biomass is richer in spiral forms and the culture medium is clean). The slurry obtained (8–10% w/v of dry weight) after filtration is washed with potable filtered water. This step is used for washing excess salts from the biomass. It amounts to 20–30% w/v of dry weight.

The final dewatering is accomplished by pressing the biomass enclosed in a piece of filtration cloth plus a strong cotton cloth, either by hand or in any kind of press. The simplest is to apply pressure (0.15 kg cm^{-2} is enough) by putting a heavy stone on the bag containing the biomass. The "juice" that is expelled comes out first colourless, later it turns green and the operation must then be discontinued otherwise too much product will be lost. For the usual thickness of cake (about one inch after pressing), the pressing time is about 15 min.

Pressed biomass contains twice as much dry matter as unpressed biomass, which reduces the drying time. The efficiency of harvest depends on the Trichome size and the mesh size of the filters used at each stage. The smaller the mesh size, the higher is the efficiency (Fox, 1996). However, flow rates are invariably lower at the higher efficiencies associated with smaller mesh filters. Increasing the force of the water

Fig. 7.2 *Spirulina* products: Various value added Spirulina forms are promoted in the market.

flow often results in breakage of cells and hence loss in efficiency and the return water has undesirable consequences in the pond culture.

The washed biomass is further concentrated by simple pressing system before being dried. Proper and quick drying is an essential feature of high-quality *Spirulina* production. Various types of drying systems are used in the industry for drying *Spirulina*. For economic reasons, the dryer of choice in large-scale *Spirulina* production facilities is the spray dryer. Freeze drying would give better overall product quality, but the cost is rather prohibitive. In spray drying, *Spirulina* droplets are sprayed in to the drying chamber just long enough to flash to the bottom. This quick spray drying process guarantees preservation of heat sensitive nutrients, pigments and enzymes (Venkataraman and Becker, 1985). Sun drying is one of the most economical systems for small projects. In this, the concentrated biomass is spread thinner in the food grade polythene sheet and is kept under hot sunlight for about 4 to 5 h. After being dried the flakes are collected and stored in the clean, moistureless, opaque containers. The grinding process is done by simple mixer grinder. Improper drying often results in high moisture content in the product. Moisture content in excess of 8 % w/w will result in the growth of moulds and bacteria in the product. Oven drying often results in the loss of some essential components like vitamins and pigments. Since the dried powder has a high sorption characteristic, the product is immediately packaged in a dry environment. The end product should have a maximum ash content of 7 %. For good preservation and storage for long period, moisture should not exceed 3–4% w/w (Fig. 7.2).

7.6 Life Cycle Analysis (LCA) of *Arthrospira plantensis*

SPRTC has carried out the life cycle assessment of the algal strain *Arthrospira platensis* grown in medium scale level at SPRTC (in the rectangular ponds and the circular ponds) and two of SPRTC's net-work *Spirulina* farms (in rectangular ponds) located at Madurai District, Tamil Nadu, India. According to the LCA-requirements, the parameters of the *Spirulina* ponds are listed as a first step and allotted the specific ponds from the regular cultivation tanks of SPRTC for regular monitoring. It is also decided that besides SPRTC's Madurai ponds, two more *Spirulina* farms in the outskirts of Madurai are included as stated above. The observation was started in all mentioned pond parameters on daily basis from November '10 in 72 m^2 (about 800 ft^2) culture area. From December '10, experimental area of culture increased to 136 m^2 (about 1500 ft^2) with the addition of new circular tank in SPRTC, Anthaneri.

Two *Spirulina* cultivation farms of SPRTC (each of 180 m^2 of production area) in March '11 at Chellampatti and Solavanthan were considered to analyse the differences for the same species at different locations and environment factors (about 35 kms from SPRTC, Anthaneri). Also in May 2012 farms at Chellampatti and Solavanthan expanded to each of 360 m^2 of production area.

Following are the important points explained in details of the technical progress:

- Maintenance of open air culture of around 150 m^2 (around 1600 ft^2) of production area in every production unit.
- Maintenance of indoor culture-mother culture in small level
  - Maintaining mother culture by daily addition of 20 % nutrient medium
  - Maintaining mother culture by daily addition of 10 % nutrient medium
- Regular monitoring and recording of pond maintenance parameters and production details
  - Inoculation details
  - Daily production details (wet weight, dry weight, water wash weight, after pressing weight, dry weight)
  - Calculating actual % of yield from wet to dry weight. Production from every square metre of area
  - Amount of nutrients added (inoculation, after harvest, troubleshooting)
  - Agitation (mixing of culture)/rotation
  - Microscopic observations (shape, size, colour, coil of *Spirulina* and presence of protozoa, rotifer, other algae)
  - Average day time temperature of pond cultures
  - Avg. viscosity of culture medium
  - Avg. pH of culture
  - Avg. culture depth
  - Dust removal/cleaning of pond
- Comparing productivity of regular tanks with that of natural resource utilized circular tanks (SPRTC has a new circular tank besides its rectangular tanks; hence it is also decided by the technical team to include it to read the differences in LCA of the same species).
- Harvest, nutrient addition, agitation, dust collection done manually in rectangular tanks
- Rotation and dust collection done automatically by wind power – Circular tanks
- Comparing productivity and other related parameters of culture maintained in various production units.

Continuous observation of open air *Spirulina* culture for the past sixteen months delivered in-depth knowledge on growth parameters of *Spirulina* such as to find out the more suitable pH, light, temperature, viscosity, average agitation per day, water quality to yield the maximum dried *Spirulina*.

The observations (Table 7.3) and the reasons are thoroughly discussed in order to have a clear understanding about the rectangular ponds of SPRTC.

- Daily production (dry)/m^2 shows that productivity of *Spirulina* was lower in monsoon and winter season (for Madurai region: October–December) and higher in summer (Figs. 7.3 and 7.4).
- Reason: *Spirulina* receives optimum range of culture temperature of 30 °C–35 °C; thus the yield is optimum at summer. Normally even in mon-

Table 7.3 Average readings/calculation monitored from the rectangular *Spirulina* ponds related yield and growth parameters of the SPRTC's Farm-1 from November 2010 to September 2012

Months	Average day production/ m^2 (g)	Avg. % of yield (%)	Average pH	Average agitation/d	Avg. day time temperature of the pond culture (°C)	Average viscosity of the culture (cp)
Nov-10	2	5.2	9.9	22	27.0	1.032
Dec-10	3.3	6.2	9.4	23	29.0	1.026
Jan-11	4.1	7.3	9.5	22	33.0	1.010
Feb-11	5.1	7	9.4	26	33.0	1.011
Mar-11	6.1	6.8	9.8	24	33.1	1.012
Apr-11	8	7.7	10.1	25	33.6	1.015
May-11	9.7	8.4	10.1	25	33.8	1.019
Jun-11	9.2	8.3	10.2	24	33.2	1.020
Jul-11	9.3	8.4	10.2	23	33.1	1.021
Aug-11	8.9	8.2	10.1	26	33.2	1.022
Sep-11	8.5	8.3	9.9	27	33.1	1.019
Oct-11	6.9	8.2	9.9	28	33.1	1.019
Nov-11	5.3	7.9	9.9	24	29.0	1.019
Dec-11	5.3	6.9	10	22	30.0	1.018
Jan-12	5.9	6.2	10	23	31.8	1.018
Feb-12	7.2	8.4	9.9	26	32.9	1.019
Mar-12	7.4	8.2	9.9	22	32.9	1.026
Apr-12	8.6	8.2	10	23	33.7	1.028
May-12	9.6	8.6	10.1	20	33.7	1.032
Jun-12	9.4	8.5	10.1	20	33.3	1.034
Jul-12	9.3	8.6	10.2	16	32.6	1.035
Aug-12	8.2	8.2	10.1	18	32.6	1.030
Sep-12	8.2	8.1	10.1	17	32.5	1.028
Oct-12	5.9	7.8	10.2	15	30.4	1.030
Nov-12	5.7	7.9	10.2	17	29.8	1.031

soon and winter we get optimum temperature (in Madurai region) but we get low light intensity which affects the productivity.

- Though productivity differs according to the factors like temperature, water quality, nutrient availability, light intensity and contaminants growth, it also

Fig. 7.3 Three different locations where LCA was carried out by SPRTC.

Fig. 7.4 Circular concrete tank of 3 m radius.

depends on other important factors like labour availability. Though it was cloudy and rainy days in monsoon like previous years, double productivity was achieved by adapting proper dual power drying system from the month September 2011.

- Also productivity in 2012 monsoon is little higher than 2011, since in 2012 monsoon was very less (7 rainy days).
- % of yield (% of dry weight from wet): It has the range 5.2–8.3 % but it adds nutrients by means of considering it as 9 %.
  - Reason: Actual is lower than the considered one since we certainly lose weight while washing and pressing processes after harvest and wastages while drying it.
  - While using solar drier the wastage ratio is very less.
- pH of the *Spirulina* culture (9.4–10.2) maintained in required normal range (9.5–10.5)
  - Reason: Ratio of addition of nutrients and utilization by *Spirulina* is quiet balanced. It ensures using good quality fertilizers (commercial grade).
- Temperature of the culture: Manual mixing of culture done frequently (22 to 28 times/d)
  - Reason: Frequent mixing of culture really helps all *Spirulina* in pond to get even sunlight, temperature and fertilizers. In spite of seasonal variations agitation helps *Spirulina* to sustain.
- Viscosity – Quiet in normal range except in monsoon seasons
  - Reason: Less productivity, less harvest, contaminants (like insect larvae, rotifer, protozoa)
    - It is necessary to take regular steps to maintain the viscosity in the optimum range by doing partial refreshment process of growing medium once in 6–8 months period.
    - It had come across some troubles like rain water mix up, windy days, invasion of other algae (*Chlorella*), insects and protozoa. It took some troubleshooting methods like refreshing the tanks with fresh medium/mother culture/healthy live mass/fertilizer addition (Figs. 7.5, 7.6 and 7.7).

The observations (Table 7.4) and the reasons are thoroughly discussed in order to have the clear understanding about the circular ponds of SPRTC.

- *Spirulina* yield/m^2 in circular tank is higher than normal rectangular tanks.
- Reason: Gentle and more frequent mixing of culture and continuous dust removal (automatic) increase the production. Temperature, viscosity and pH of culture are maintained in normal range. The average yield was 8 % but after addition of nutrients it was 9 %.
- Viscosity – Quiet in normal range (1.010–1.029 cp)

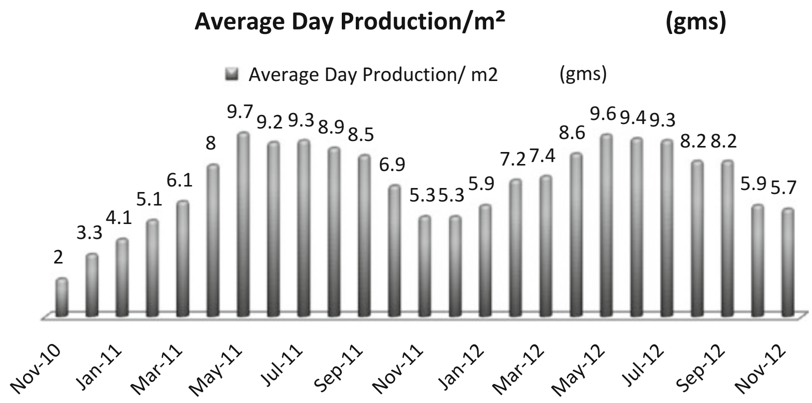

Fig. 7.5 The variation of algal biomass productivity in different months.

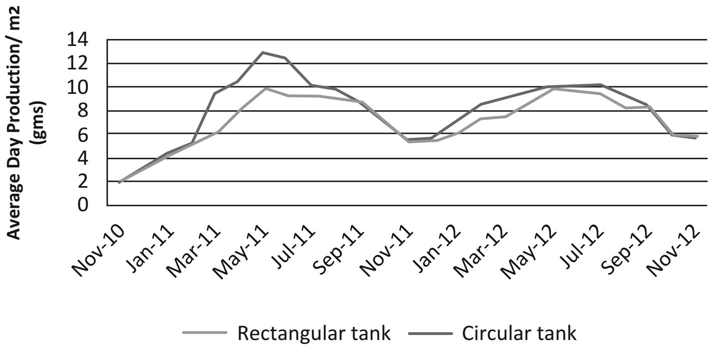

Fig. 7.6 Comparison of production between rectangular and circular tanks.

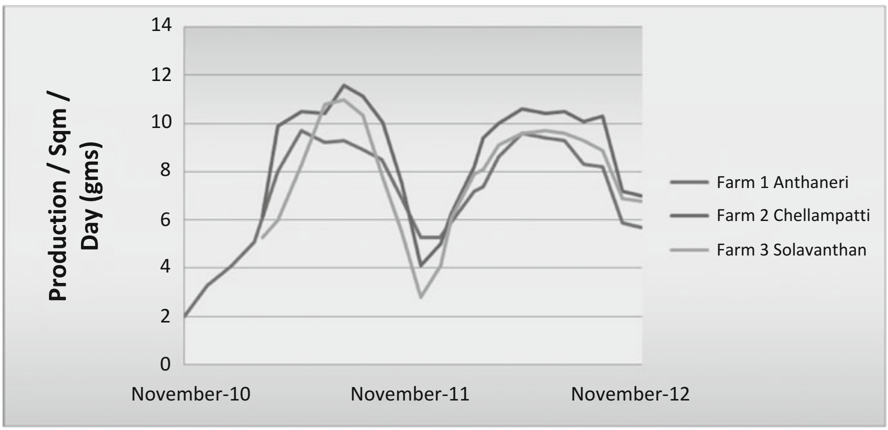

Fig. 7.7 Comparison of the yield of dry Spirulina from three different farms.

Table 7.4 Productivity details and other related parameters of Farm-1 *Spirulina* (grown in circular tank)

Month	Average day production/ m^2 (g)	Avg. percentage of yield (%)	Average pH	Agitation /d	Avg. day time temperature of the pond culture (°C)	Average viscosity of the culture (cp)
10-Nov						
10-Dec	3.2	2.3	9.5	37	29	1.01
11-Jan	4.4	7.7	9.5	41	33	1.01
11-Feb	5.1	8.6	9.6	51	33	1.01
11-Mar	9.5	7.8	9.8	60	33	1.011
11-Apr	10.5	8.3	10.1	101	33.8	1.016
11-May	12.9	8.5	10.1	102	33.6	1.016
11-Jun	12.4	8.4	10.2	102	33.5	1.016
11-Jul	10.2	8.3	10.1	118	33.2	1.022
11-Aug	9.8	8.3	10.1	132	32.6	1.021
11-Sep	8.7	8.4	10.3	146	34.5	1.021
11-Oct	6.9	8.2	10.3	146	34.4	1.021
11-Nov	5.6	7.9	10.2	128	29.8	1.02
11-Dec	5.7	7.5	10.1	120	29.7	1.02
12-Jan	7.2	8.5	10.2	138	31.5	1.021
12-Feb	8.4	8.6	10.3	141	33.1	1.022
12-Mar	8.9	8.3	10.1	126	33.1	1.024
12-Apr	9.7	8.4	10.1	119	33.6	1.027
12-May	10.1	8.2	10	118	33.8	1.024
12-Jun	10.3	8.2	10.1	117	33.4	1.028
12-Jul	10.2	8.1	10.2	64	32.7	1.029
12-Aug	9.1	8.2	9.8	74	31.4	1.028
12-Sep	8.4	8	9.7	75	31.2	1.028
12-Oct	7.7	7.8	10	80	30	1.027
12-Nov	7	7.6	10	82	29.7	1.028

- The culture maintained in the regular tanks requires refreshment of the medium once in 6–8 months time period. But for the culture maintained in the circular tank, it does not require medium refreshment (partial/complete).
- pH of the *Spirulina* culture (9.5–10.3) maintained is required in normal range (9.5–10.5)
- Reason: Ratio of addition of nutrients and utilization by *Spirulina* is quiet balanced. It also ensures using good quality fertilizers (commercial grade) and mixing.
- Manual mixing of culture done frequently (avg. 103 times/d).
  - Reason: Frequent rotation of culture really helps all *Spirulina* in pond to get even sunlight, temperature and fertilizers. We could manage rotation per day in circular tank much higher than normal agitation per day in normal rectangular tanks. So, it helps a lot to maintain the culture's viscosity for many more days in normal range.
- Yield at Farm 2, Chellampatti is higher than other two farms though the temperature, viscosity, and nutrient addition and agitation are maintained same as other farms.
  - Reason: Water quality and sunlight availability are better than other farms.
- Annual average of yield at Farm 3 is quiet low as same as Farm 1, though the water quality and other environmental factors match with Farm 2.
  - Reason: Lack of labour availability – regular maintenance (Table 7.5).

7.7 Summary and Conclusion

As SPRTC begun monitoring its proposed LCA of the algal strain, *Arthrospira platensis* since November 2010, this was initially carried out with the rectangular ponds of SPRTC, then the circular pond parameters were also included and compared during this research. Later from March two new farms located in the outskirts of Madurai have been included and all the parameters were monitored at both locations. The data recorded are being compared with SPRTC's Madurai unit and two other units which give a clear understanding about the factors influencing the growth of the algal strains. The important points and findings from November 2010 to November 2012 are thoroughly listed in the tables and discussed with the explanations at all the relevant places. SPRTC is happy to learn from the records of the past twenty five months that the research carried out is more helpful to optimize the production, reduce the expenditures on feeding some nutrients as the environment factors are the main regulators of the growth of the algal strains in most times.

Table 7.5 Yield comparison of dry *Spirulina* from three different *Spirulina* farms

	Production, g m^{-2} d^{-1}		
Month	Farm 1 Anthaneri	Farm 2 Chellampatti	Farm 3 Solavanthan
November-10	2		
December-10	3.3		
January-11	4.1		
February-11	5.1		
March-11	6.1	6.2	5.3
April-11	8	9.9	6
May-11	9.7	10.5	8.3
June-11	9.2	10.4	10.8
July-11	9.3	11.6	11.0
August-11	8.9	11.1	10.3
September-11	8.5	10.0	7.8
October-11	6.9	7.6	5.5
November-11	5.3	4.1	2.8
December-11	5.3	5.0	4.1
January-12	5.9	6.3	6.1
February-12	7.2	8.2	7.9
March-12	7.4	9.4	8.1
April-12	8.6	10	9.1
May-12	9.6	10.6	9.6
June-12	9.4	10.4	9.7
July-12	9.3	10.5	9.6
August-12	8.3	10.1	9.3
September-12	8.2	10.3	8.9
October-12	5.9	7.2	6.9
November-12	5.7	7	6.8

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