12 Household Detergents Causing Eutrophication in Freshwater Ecosystems

Abid A. Ansari and Fareed A. Khan

Abstract

In the present study, the impact of some selected household detergents has been studied on the growth behavior and development of two freshwater duckweeds, namely *Lemna minor* and *Spirodela polyrrhiza*. The growth responses of these selected free-floating duckweeds to varying concentrations of "Surf Excel" (the most commonly used detergent) have been studied with special reference to varying temperature and pH. There were three predominant types of growth pattern of both the selected duckweeds treated with 36 selected detergents. Some of the detergents increased the growth of the two duckweeds in almost logarithmic progression showing increase in growth with increasing concentration (10–50 ppm). A few detergents increased growth of both the selected duckweeds to a certain level of detergent concentration and then the growth became stationary with further increase in detergent concentration. In the third type of response, the duckweed growth initially increased in response to a certain level of detergent concentration and declined at higher detergent concentration. It was inferred from the observations that detergents play important role in promoting the growth of duckweeds. Out of 36 detergents studied, certain detergents effectively promoted the growth of duckweeds even in low concentration. Certain brands of detergents resulted in consistent increase in the growth with increasing concentration. The temperature effectively modified the duckweed response to the detergent. The cooler water medium had lesser degree of eutrophication than the moderately warm water medium. Not the phosphorus content alone, but the water quality (turbidity, pH, nutrient concentration, and dissolved oxygen) modified by the detergent aggravated the problem of eutrophication. Therefore, the water bodies receiving acids from any source in addition to detergent are more likely to show a greater degree of eutrophication than a body receiving detergent without acids.

Keywords

Eutrophication · *Lemna minor* · *Spirodela polyrrhiza* · Detergents

12.1 Introduction

The water is an essential life supporting matter in every cell of an organism. It enters into the living organisms via absorption or ingestion. It circulates between biotic and abiotic components of the ecosystem. The misuse and reckless over consumption has resulted into the fast depletion of water resources (Ansari and Khan 2007). The nutrient enrichment of the water bodies caused from the natural and man-made

F. A. Khan (✉)
Department of Botany, Aligarh Muslim University,
Aligarh 202002, India
e-mail: fareedkhan.amu2007@rediffmail.com

A. A. Ansari
Department of Biology, Faculty of Science, University of Tabuk,
Tabuk, Kingdom of Saudi Arabia

A. A. Ansari, S. S. Gill (eds.), *Eutrophication: Causes, Consequences and Control,*
DOI 10.1007/978-94-007-7814-6_12,

sources is depleting the water resources at a faster pace. The eutrophication is a kind of nutrient enrichment process of any aquatic body which results into an excessive growth of phytoplankton (Ansari and Khan 2006a). The phosphate rocks and mineral sedimentation are the natural sources of phosphorus into the terrestrial and aquatic ecosystems. The household detergents containing phosphates and phosphorus fertilizers used in the agricultural practices are the major anthropogenic sources of phosphorus (Ansari 2005).

Eutrophication is one of the serious kinds of water pollution directly affecting the fauna owing to the loss of dissolved oxygen level. It leads to an early and relatively faster mortality rate of fishes and thus spoils the desired water qualities of ponds or lakes. The fishing operation and navigation becomes difficult owing to enmeshed and heavy growth of plants. The hydroelectric generation from such water storages is adversely affected as nutrient-rich water (of such reservoirs) acts chemically upon the turbines (Khan and Ansari 2005). At the end of algal bloom, the decomposing debris also spoils the desired water characteristics and may bring in the growth of disease-causing bacteria. An uncontrolled eutrophication leads to a rapid upwelling of a water body (Ansari and Khan 2009a, b). The limited storage and water recharging capacity of smaller freshwater bodies reduces by silting. Small lakes and many ponds steadily lose their aquatic entity and become permanently terrestrial in nature (Ansari et al. 2011a, b).

The common household detergents are the major anthropogenic source of phosphorus input into the nearby water bodies and sewage treatment plants. The detergents normally consist of two basic components the surfactants and the builders. The surfactants also called surface-active agents are the main cleaning agents. We can find various brands of detergents in the markets containing 10–30 % surfactants (Rao 1998; Khitoliya 2004). The remaining parts of detergents are the builders as polyphosphate salts. About 1 ppm of surfactant produces a huge amount of foam in water bodies. This concentration is non-toxic to human being but gives an off-taste to drinking water and exerts a significant impact on ecosystem. Just 0.1 ppm of surfactant can reduce the rate of oxygen absorption in water to about half (Rao 1998).

Chemically the surfactants are linear alkyl sulphonate. At present, the release of polyphosphate builders into natural water is great environmental problem than the surfactants. It causes eutrophication of the water bodies in which it is released. Nitrilotriacetate was considered to be a replacement of polyphosphate builder but it proved to be hazardous to human health. The best alternative is to minimize the use of phosphates in detergents (Rao1998).

The members of the duckweeds family Lemnaceae are small free-floating plants which propagate rapidly. They are very sensitive to many factors of surrounding environment (Lau and Lane 2002a, b). Their potentials to use as indicators of water quality have been studied by several workers (Ansari and Khan 2011c; Srivastava and Jaiswal 1989). Duckweeds are appropriate material for the investigation of metal accumulation and its toxicity. The duckweeds change their morphology growth rate in response to even a very small amount of water pollutant (Ansari and Khan 2008; Jaiswal and Srivastava 1987). On certain criteria Thornton et al. (1986) considered *Lemna minor* as ecologically sensitive species. The growth of *Spirodela polyrrhiza* was found directly related with the type and nature of the water (Ansari and Khan 2002). Duckweed species are promising macrophytes for the use in sustainable wastewater treatment owing to their rapid growth, ease of harvest and feed potential as a protein source. The duckweeds showed a high growth rate and productivity in well-managed system (Ansari and Khan 2009b, 2011d; Edwards 1985, 1992). The duckweeds have been found responsible for three-quarters of the total nitrogen (N) and phosphorus (P) loss in very shallow aquatic systems (Korner et al. 2003) and thus have potentials of phytoremediation. The duckweed growth shows a direct response to the chemical composition of water (Landolt 1986). Wastewater concentrations and seasonal climate conditions had direct impacts on duckweed growth and nutrient uptake by these plants (Cheng et al. 2002).

In the present work experiments were designed to study the extent of eutrophication caused by 36 selected household detergents in the fresh water ecosystem. The growth behavior of the selected duckweeds namely *Lemna minor* (L.) and *Spirodela polyrrhiza* (L.) of family Lemnaceae was studied as a measure of eutrophication caused by detergents. In the present work, growth behavior of both the free-floating duckweeds have been studied with special reference to "Surf Excel" detergent powder commonly used in India.

12.2 Materials and Methods

12.2.1 Selection and Collection of Plant Material

The two common duckweeds namely *Lemna minor* (L.) and *Spirodela polyrrhiza* (L.) Shield of family Lemnaceae were selected for the experiments. The individuals of both the species were collected with the help of tea strainer from the fresh water bodies of civil line area of Aligarh. Both the selected duckweeds were brought to the laboratory in separate polyvinyl containers with adequate quantity of water. The collected duckweeds were washed 3–4 times with tap water.

12.2.2 Botanical Description of Selected Plants (Pandey 1997)

12.2.2.1 *Lemna minor* (L.)

Habit They are the smallest and least differentiated angiosperms of the world. They are aquatic in nature and found floating in fresh waters.

Diversity and distribution The species of *Lemna* are widely distributed in both temperate and tropical parts of the globe except in arctic regions.

Plant morphology The plant body consists of green dorsiventral scale like shoots. The shoots of *Lemna* range from 1/8 to 3/4 in. The plants do not possess leaves and flat green shoot perform the functions of leaf. The plant body may easily be differentiated into a basal portion with two lateral pockets from which the branches arise. From the ventral surface of the flattened stem a single adventitious root come out. The apex of root is converted by a few layered sheaths (root cap) which is visible to the unaided eyes.

The internal structure of the shoot is spongy in nature and consists of parenchymatous cells. These cells remain separated from each other by large or small air spaces, which communicate with the outside by stomata on the upper surface. Vascular tissue is represented by a single median vascular bundle of very simple structure.

Inflorescence In temperate zones, the flowers are rarely developed. The inflorescence is quite simple and arises in the pocket.

Flowers The flowers are unisexual. The plants are monoecious, i.e., both male and female flowers develop in the same inflorescence. The flowers are without perianth (naked). The male flower consists of single stamen. The filament is stout bearing at its apex a pair of dithicous anther-halves. The pollen grains are spherical and covered with small warty outgrowths. The female flower consists of single carpel. The pistil is flask shaped with a short funnel-shaped stigma. The ovary is unilocular with one to six basal, erect, orthotropous, or more or less completely anatropous ovules.

Fruit Inconspicuous, usually one seeded.

Seed The seed possess a thick fleshy outer and a thin inner coat. The embryo consists of a large cotyledon surrounded by scanty endosperm.

Pollination The pollination is affected by wind, water, or animals.

Propagation New plant buds arise from the pockets on either side of the parent plant and eventually break apart. Over winters as winter buds on the lake bottom, but rarely reproduces from seeds. A plant can reproduce itself about every 3rd day under ideal conditions in nutrient rich waters.

Importance of plant Food for fish and waterfowl and habitat for aquatic invertebrates. Because of its high nutritive value, duckweeds have been used for cattle and pig feed in Africa, India, and southwest Asia. They are also used to remove nutrients from sewage effluents.

12.2.2.2 *Spirodela polyrrhiza* (L.) Shield

Habit They are the smallest and least differentiated angiosperms of the world. They are aquatic in nature and found floating in fresh waters.

Diversity and distribution The species of *Spirodela* are widely distributed in both temperate and tropical parts of the globe except in arctic regions.

Plant morphology The plant body consists of green dorsiventral scale-like shoots. There are no leaves and flat green shoot perform the functions of leaf. The plant body (thallus) is actually an expended “stem” which functions as leaf. It is oval to oblong, has 5–12 distinct veins and is 4–10-mm long. The thallus is glossy green and smooth on the upper surface and reddish purple below. Clusters of 4–16 slender fibrous roots hang below the surface of the water from each plant. Each roots ends with a pointed root cap.

The internal structure of the shoot is spongy in nature and consists of parenchymatous cells. These cells remain separated from each other by large or small air spaces, which communicate with the outside by stomata on the upper surface. Vascular tissue is represented by a single median vascular bundle of very simple structure.

Inflorescence In temperate zones, the flowers are rarely developed. The inflorescence is quite simple and arises in the pocket.

Flowers The flowers are unisexual. The plants are monoecious, i.e., both male and female flowers develop in the same inflorescence. The flowers are without perianth (naked). The male flower consists of single stamen. The filament is stout bearing at its apex a pair of dithicous anther-halves. The pollen grains are spherical and covered with small warty outgrowths. The female flower consists of single carpel. The pistil is flask shaped with a short funnel-shaped stigma. The ovary is unilocular with one to six basal, erect, orthotropous, or more or less completely anatropous ovules.

Fruit A ribbed seed develops in a balloon like bag (utricle).

Seed The seed possess a thick fleshy outer and a thin inner coat. The embryo consists of a large cotyledon surrounded by scanty endosperm.

Pollination The pollination is affected by wind, water or animals.

Propagation Reproduces quickly by asexual budding, seeds and over winters as dark green or buds on the sediments.

Importance of plant Provides a high protein food source for ducks and geese, also eaten by certain fish in Africa and Asia, giant duckweed has been harvested for cattle and pig feed. Grows quickly, especially the water is warm and nutrient enriched. It has been used to reduce nutrients in sewage effluents.

12.2.2.3 Classification of *Lemna minor* and *Spirodela polyrrhiza* (Pandey 1997)

12.2.3 Culture and Stock of the Selected Duckweeds

Bentham and Hooker (1862)	Engler and Prantl (1931)	Hutchinson (1959)
Phanerogams	Phanerogams	Angiospermeae
Monocotyledones	Monocotyledoneae	Monocotyledones
Nudiflorae	Spathiflorae	Corolliferae
Lemnaceae	Lemnaceae	Arales
–	–	Lemnaceae

The plants of *Lemna minor* (L.) and *Spirodela polyrrhiza* (L.) grow vegetatively and quickly. The duckweeds collected were cultured in larger bowl-shaped earthen pots locally called as *Nand*. The approximate size of these pots was 40-cm diameter, 25-cm depth and 19 L capacity. The pots were filled with 15 L of tap water. After a lag phase of 24 h, 15 mL macronutrient (Hoagland) solution (Mahadevan and Sridhar 1986), 1 mL of water was added in culture pots (Table 12.1). The total volume of 15 L of water in the earthen pot was maintained every 24 h by maintaining the marked water level. The pure stock/culture of single duckweed was separately maintained by constant removing of any other weed appearing in the pure culture.

Table 12.1 Stock solution of macronutrients (Hoagland solution)

Macronutrients	g/L
$NH_4H_2PO_4$	0.23
KNO_3	1.02
$Ca(NO_3)$	0.492
$MgSO_47H_2O$	0.49

12.2.4 Setting of Experimental Pots

The required individuals of *Lemna minor* and *Spirodela polyrrhiza* (of approximately mature body size) were carefully transferred from the maintained duckweed stocks to the experimental pots (filled with detergent solution of varying concentration and Trade brands) with the help of small painting brush (No. 2).

12.2.5 Treatments and Detergent Solution

In the screening experiment the selected duckweeds were treated with three concentrations of commonly available detergents under 36 brand names (Table 12.2). In the screening experiments 10 ppm, 30 ppm, and 50 ppm of each detergent were prepared in tap water and used as T_1, T_2, and T_3. A control as T_0 having no detergent but the tap water was also maintained for the reference (Tables 12.3, 12.4). In rest of the experiments, the growth performances of the selected duckweeds were studied in five varying concentrations of a selected detergent "Surf Excel" and a control (tap water).

The treatment named as T_0 consisted of simple tap water (without detergent). The treatments T_1, T_2, T_3, T_4, and T_5 consisted of 10, 20, 30, 40, and 50 ppm of "Surf Excel" in tap water, respectively (Tables 12.3 and 12.4). The required detergent solutions were prepared from the 100 mL stock solutions of 1, 2, 3, 4, and 5 % of detergent cakes or powders in tap water by further dilutions. Owing to hygroscopic nature, the detergent cakes and powders used in the present experiments were oven dried at 60 ° for 24 h before weighing.

12.2.6 Experiments Designed

The first two experiments were designed to work out the growth response (in terms of dry weight) of the selected duckweeds to varying concentrations of the 36 selected detergents dissolved in the tap water (Tables 12.2, 12.3 and 12.4). The first screening experiment was conducted on *Lemna minor* and second on *Spirodela polyrrhiza*. In the screening experiment with *Lemnaminor* and *Spirodela polyrrhiza,* 1 g of each plant of almost equal size were transferred from the maintained pool to polyvinyl pots of containing 500 mL of the detergent solution (of a desired concentration). The pots of each detergent and their concentration were maintained in

Table 12.2 List of the detergent products used in screening experiments

S. No.	Brand Name	Form	Product by
1	Ariel	Cake	Procter and Gamble Home Products Ltd. Mumbai
2	Ariel	Powder	Procter and Gamble Home Products Ltd. Mumbai
3	Budget	Cake	Kothari detergent Ltd. Kanpur
4	Doctor	Cake	P.C.Cosma Soap Pvt. Ltd. New Delhi
5	Doctor	Powder	P.C.Cosma Soap Pvt. Ltd. New Delhi
6	Double Dog	Powder	KTC Pvt. Ltd. Kanpur
7	Cleano	Powder	Garud Homo-Cleanse Pvt. Ltd. Delhi
8	Fena	Cake	Fena Pvt. Ltd. New Delhi
9	Fena	Powder	Fena Pvt. Ltd. New Delhi
10	Friendly Wash	Powder	Henkel Spic India Ltd. Chennai
11	555	Cake	GoramalHariram Ltd. New Delhi
12	Ghari	Cake	KTC Pvt. Ltd. Kanpur
13	Ghari	Powder	KTC Pvt. Ltd. Kanpur
14	Henko	Cake	Henkel Spic India Ltd. Chennai
15	Henko	Powder	Henkel Spic India Ltd. Chennai
16	Maxclean	Powder	Wiseman Home Products
17	Mor	Cake	Sagar Detergent Pvt. Ltd. Kanpur
18	Mor	Powder	Sagar Detergent Pvt. Ltd. Kanpur
19	Morlight	Powder	Sagar Detergent Pvt. Ltd. Kanpur
20	Mr. White	Powder	Henkel Spic India Ltd. Channai
21	Nirma	Cake	Nirma Ltd. Ahmadabad
22	Nirma	Powder	Nirma Ltd. Ahmadabad
23	Nirma Super	Powder	Nirma Ltd. Ahmadabad
24	Plus	Cake	Corona Plus Inds. Ltd. Mumbai
25	Plus	Powder	Corona Plus Inds. Ltd. Mumbai
26	Plus (Extra)	Powder	Corona Plus Inds. Ltd. Mumbai
27	Plus (Saving)	Powder	Corona Plus Inds. Ltd. Mumbai
28	Rin	Cake	Hindustan Lever Ltd. Mumbai
29	Rin Shakti	Powder	Hindustan Lever Ltd. Mumbai
30	Rin Supreme	Powder	Hindustan Lever Ltd. Mumbai
31	Surf	Powder	Hindustan Lever Ltd. Mumbai
32	Surf Excel	Powder	Hindustan Lever Ltd. Mumbai
33	Tide	Powder	Procter and Gamble Home Products Ltd. Mumbai
34	Time-Zee	Powder	Ramnagar Khadi Gram udyog Samiti. Chandauli
35	Wheel	Cake	Hindustan Lever Ltd. Mumbai
36	Wheel	Powder	Hindustan Lever Ltd. Mumbai

triplicates. The duckweeds were allowed to grow for another 10 days. The day of transfer of plants was counted as day-1. The experiments were terminated on 11th day and plants were harvested, dried in oven at 80 °C for 24 h and weighed (as per the scheme given in Table 12.4).

The detailed studies on the responses of the two selected weeds to 0, 10, 20, 30, 40, and 50 ppm of Surf Excel were carried out in large earthen pots (locally called as *Nand*) filled with 15 L of the detergent solution (Table 12.4). In these pots 5 g of *Lemna minor* and *Spirodela polyrrhiza* were inoculated in separate experiments on day 1st from the pure duckweed stocks. Growth of *Lemna minor* and *Spirodela polyrrhiza* was recorded at 11th day of transplant in the pots. The uptake of NPK, chlorophyll content (*a*, *b*, and total), dry weight and physico–chemical properties of detergent solutions were also determined after the termination of experiments on 11th day (Table 12.4).

Table 12.3 Scheme of treatments of the selected duckweeds with varying concentrations of detergent in various experiments conducted in polyvinyl and earthen pots.

Treatments (each in triplicate)	Screening experiment with the listed 36 detergents	Experiment with Surf Excel
T_0 (control)	0 ppm (tap water only)	0 ppm (tap water only)
T_1	10 ppm	10 ppm
T_2	30 ppm	20 ppm
T_3	50 ppm	30 ppm
T_4	–	40 ppm
T_5	–	50 ppm

Two separate experiments were conducted in polyvinyl pots to evaluate the effect of temperature variation (viz.10, 20, 30, 40 and 50 °C) and its interaction with varying concentrations of Surf Excel detergent on growth responses of duckweeds. The polyvinyl pots inoculated with 1 g of *Lemna minor* or *Spirodela polyrrhiza* were placed in BOD incubator (Caltan, Narang Scientific Works Pvt. Ltd., New Delhi) for the temperature treatments maintained at 10, 20, 30, 40, or 50 °C. The growth in all pots was recorded after the termination of the experiments (Table 12.4). Owing to early mortality of *Lemna minor* at higher temperatures 40 and 50 °C, the growth parameters were recorded finally at 7th and 5th day, respectively. These parameters of *Spirodela polyrrhiza* maintained at 40 and 50 °C temperature were finally recorded at 9th and 5th day, respectively. The plants with maximum brownish or yellowish appearance (chlorosis) were treated as dead.

Two experiments were conducted to study the effect of pH variation on the responses of selected duckweeds to varying levels of Surf Excel detergent in the ecosystem at a given temperature. The pH of detergent solutions and tap water was maintained at pH 6.0, 6.5, 7.0, 7.5, and 8.0 by using NaOH or HCl. The data on growth parameters were recorded as in previous experiments (Table 12.4).

12.2.7 Data Recording

The data on growth of both the selected species in all sets of experiments were recorded at 11th day stage. The water and plant analysis was also carried out after the termination of experiments (on 11th day or earlier as in experiments with temperature treatments). The data so obtained were analyzed

Table 12.4 A summary of the designed experiments

Species and individuals inoculated at day-1	Treatments (detergent in tap water)	Pot type, Volume and replicates	Parameters studied
Lemna minor, 1 g individuals in each **polyvinyl pot**	0 (control), 10, 30 and 50 ppm of the 36 selected detergents (solution 500 ml)	Polyvinyl pots, 500 mL, 3 replicates	Dry weight after termination, at 11th day
Spirodela polyrrhiza, 1 g individuals in each **polyvinyl pot**	0 (control), 10, 30 and 50 ppm of the 36 selected detergents (solution 500 ml)	Polyvinyl pots, 500 mL, 3 replicates	Dry weight after termination, at 11th day
Lemna minor, 5 g individuals in each *earthen pot*	0 (control), 10, 20, 30, 40 and 50 ppm of Surf Excel detergent powder (solution 15 L)	Earthen pots, 15 L (Nand), 3 replicates	Growth parameters and uptake of NPK at 11th day, water analysis
Spirodela polyrrhiza, 5 g individuals in each **earthen pot**	0 (control), 10, 20, 30, 40 and 50 ppm of Surf Excel detergent powder (solution 15 L)	Earthen pots, 15 L (Nand), 3 replicates	Growth parameters and uptake of NPK at 11th day, water analysis
Lemna minor, 1 g individuals in each **polyvinyl pot**	Temperature variations, 10, 20, 30, 40 and 50 °C at each treatment level (0, 10, 20, 30, 40 and 50 ppm) of Surf Excel, pH constant = 7.0	Polyvinyl pots, 500 mL, 3 replicates	Growth parameters and uptake of NPK at 11th day, water analysis[a]
Spirodela polyrrhiza, 1 g individuals in each **polyvinyl pot**	Temperature variations,10, 20, 30, 40 and 50 °C at each treatment level (0, 10, 20, 30, 40 and 50 ppm) of Surf Excel, pH constant = 7.0	Polyvinyl pots, 500 mL, 3 replicates	Growth parameters and uptake of NPK at 11th day, water analysis[b]
Lemna minor, 1 g individualsin each **polyvinyl pot**	pH variations, 6.0, 6.5, 7.0, 7.5 and 8.0 at each treatment level (0, 10, 20, 30, 40 and 50 ppm) of Surf Excel, temperature constant = 30 °C	Polyvinyl pots, 500 mL, 3 replicates	Growth parameters and uptake of NPK at 11th day, water analysis
Spirodela polyrrhiza, 1 g individuals in each **polyvinyl pot**	pH variations, 6.0, 6.5, 7.0, 7.5 and 8.0 at each treatment level (0, 10, 20, 30, 40 and 50 ppm) of Surf Excel, temperature constant = 30 °C	Polyvinyl pots, 500 mL, 3 replicates	Growth parameters and uptake of NPK at 11th day, water analysis

[a] The *Lemna minor* showed an early maturity and death (complete chlorosis) at 40 and 50 °C. The growth parameters and uptake of NPK at 40 and 50 °C were recorded at 7th and 5th day, respectively after the death of the plants

[b] The *Spirodela polyrrhiza* showed an early maturity and death (complete chlorosis) at 40 and 50 °C. The growth parameters and uptake of NPK at 40 and 50 °C were recorded at 9th and 5th day, respectively after the death of the plants

statistically following Dospekhov (1984) for mean ± standard deviation, percent variation, and significance of the variation over control.

12.2.8 Parameters Studied

The following parameters were studied:

12.2.8.1 Characteristics of the Varying Concentrations of Detergent Solution

1. Turbidity
2. pH
3. Dissolved oxygen
4. Nitrates
5. Phosphates
6. Potassium

12.2.8.2 Growth Parameters

1. Dry weight of plant
2. Chlorophyll *a*
3. Chlorophyll *b*
4. Total chlorophyll

12.2.8.3 Nutrient Uptake in Plants

1. Nitrogen content
2. Phosphorus content
3. Potassium content

Characteristics of Varying Grades of Detergent Solutions

The water analysis of varying grades of detergent solution was carried out following Trivedi et al. (1987). The turbidity, pH, dissolved oxygen, nitrates, phosphates, and potassium contents of detergent solution were analyzed after the termination of experiments.

1. pH

The pH was determined with the help of pH meter (Elico, Elico Ltd. Hyderabad, India). The pH meter was calibrated with standard buffer of known pH before use.

2. Turbidity

Turbidity was determined with the help of Nephroturbidity meter (Elico, Elico Ltd. Hyderabad, India). The turbidity meter was calibrated with the standard solutions of known turbidity.

3. Dissolved oxygen (DO)

Dissolved oxygen content was calculated with the help of following formula:

$$\mathrm{DO} = \frac{(\mathrm{ml} \times \mathrm{N})\ \text{of sodium thiosulphate} \times 8 \times 1000}{V_2[(V_1 - V)/V_1]}\ \mathrm{mg/l}$$

Where, V_1 = volume of sample bottle

V_2 = volume of content titrated

V = volume of $MnSO_4$ and KI added (2 mL) to the sample

4. Nitrates
Nitrates were calculated from the standard pattern. Standard pattern was prepared between concentration of nitrates and absorbance from 0.0 to 1.0 mg/L of nitrates at the NO_3-N at the interval of 0.1 by finding the absorbance of standards.
5. Phosphates
The concentration of phosphate calculated with help of standard pattern. The standard pattern was prepared in the range of 0.0 to1.0 mg/L of PO_4-P at the interval of 0.1, following the same method described for the NO_4-N.
6. Potassium
The estimation of potassium was carried out directly with the help of flame photometer (AIMIL, Aimil Sales and Agencies Pvt. Ltd., New Delhi) using appropriate filter and a standard pattern by taking known concentration of potassium.

Growth Parameters
1. Dry weight of plant
Plants dried at 80 °C for 24 h after the termination of experiment and dry weight was taken per gram of fresh material.
2. Chlorophyll estimation
The optical density of chlorophyll solution read at 645 nm and 663 nm wave lengths with the help of Spectronic-20 Spectrophotometer (Elico, Elico Ltd. Hyderabad, India). The chlorophyll contents were calculated according to the formula given by Arnon (1951) as given below:

$$\text{Chlorophyll } a\left(\text{mg/g of fresh tissue}\right) = \frac{12.7\,(\text{O.D.663}) - 2.69\,(\text{O.D.645}) \times \text{V}}{1000 \times \text{W}}$$

$$\text{Chlorophyll } b\left(\text{mg/g of fresh tissue}\right) = \frac{22.9\,(\text{O.D.645}) - 4.68\,(\text{O.D.663}) \times \text{V}}{1000 \times \text{W}}$$

$$\text{Total Chlorophyll}\left(\text{mg/g of fresh tissue}\right) = \frac{20.2\,(\text{O.D.645}) + 8.02\,(\text{O.D.663}) \times \text{V}}{1000 \times \text{W}}$$

Where, O.D. = optical density (absorbance) at given wave lengths viz. 645 and 663 nm.
V = total volume of chlorophyll extract prepared in 80 % acetone.
W = fresh weight of plant tissue in g.

Nutrient Uptake
To determine the nutrient uptake of plant the samples were digested according to Lindner (1944) for the estimation of N, P, and K.
1. Estimation of nitrogen
The nitrogen was estimated following the method of Lindner (1944). The solution of standard pattern and samples were read for their absorbance at 525 nm using Spectronic-20 Spectrophotometer. A calibration pattern was plotted with optical density on X-axis and known concentration of ammonium sulfate on Y-axis, nitrogen was expressed in terms of percentage on dry matter bases.
2. Estimation of phosphorus
Phosphorus contents in digested material were estimated by the method of Fiske and Subbarow (1925). Optical density of the solution (sample) was read at 625 nm using Spectronics-20 Spectrophotometer. A standard pattern was prepared using different dilutions of KH_2PO_4 solution versus optical density. With the help of standard pattern the content of phosphorus in terms of percentage on dry matter base was determined.
3. Estimation of potassium
The potassium contents were estimated by Flamephotometer (Elico, Elico Ltd. Hyderabad, India). The readings were compared with the help of calibration pattern plotted with the help of known dilutions of KCl solution. The potassium was expressed in terms of percentage on a dry weight bases.

12.3 Observations

In the present work, impact of 12 detergent cakes and 24 detergent powders commonly sold in the Indian market on the growth (in terms of dry weight) of selected duckweeds namely *Lemna minor* and *Spirodela polyrrhiza* have been studied. The growth responses of the selected duckweeds maintained in small plastic pots containing varying concentrations of all the selected detergents are given below. In both the weeds three general types of pattern of absolute growth were observed (as given).

12.3.1 Growth Pattern

There were three general types of absolute growth pattern as **type-A**, **type-B**, and **type-C** observed in the duckweed growth treated with 36 selected detergents. Type-A pattern shows a consistent increase in growth of the duckweed with increasing concentration of some detergents. The peak of growth was recorded at 50 ppm level of detergent. Type-B growth pattern shows an increase in growth up to 30 ppm and then a decline at higher concentration. In type-C growth pattern there was an increase in the duckweed growth at lower dose (10 ppm) of detergents and then it decreased with further detergent concentration. Type-A pattern of growth resemble with the growth pattern of algal bloom in a medium with unlimited environment (Kormondy 1994). The growth pattern type-A is closer to positive linear line between the growth and detergent concentration. The *Lemna minor* and *Spirodela polyrrhiza* treated with a large number of detergent cakes showed predominantly growth pattern type-A

Table 12.5 Dry weight (mg g^{-1} of fresh weight) of *Lemna minor* treated in small plastic pots with varying doses of 12 selected detergent cakes

Detergent (Brand name)	Control	Concentration (ppm)			LSD at	
	0	10	30	50	5%	1%
Ariel	113.54±1.04	114.62±1.0 (+0.95%)	118.67±1.37 (+4.52%)	116.27±1.40 (+2.40%)	0.86	1.30
Budget	113.54±1.04	114.98±1.90 (+1.27%)	116.49±1.72 (+2.60%)	115.46±1.20 (+1.69%)	1.60	2.43
Doctor	113.54±1.04	115.69±1.06 (+1.89%)	117.75±1.53 (+3.71%)	116.08 ±1.2 (+2.24%)	0.58	0.88
Fena	113.54±1.04	117.79±1.72 (+3.74%)	113.69±0.62 (+0.13%)	114.33±1.31 (0.70%)	2.51	3.81
555	113.54±1.04	114.90±1.05 (+1.20%)	115.52±1.45 (+1.74%)	113.84±1.46 (+0.26%)	NS	NS
Ghari	113.54±1.04	115.31±1.54 (+1.56%)	115.21±1.26 (+1.47%)	114.75±0.96 (+1.07%)	0.66	1.00
Henko	113.54±1.04	113.89±1.10 (+0.31%)	119.77±1.57 (+5.49%)	115.44±0.91 (+1.67%)	0.71	1.08
Mor	113.54±1.04	115.01±1.08 (+1.29%)	115.87±0.73 (+2.05%)	114.51±1.33 (+0.85%)	NS	NS
Nirma	113.54±1.04	116.12±1.13 (+2.27%)	120.43±1.22 (+6.07%)	115.40±0.73 (+1.64%)	0.53	0.80
Plus	113.54±1.04	116.56±0.60 (+2.66%)	115.37±1.31 (+1.61%)	113.96±1.27 (+0.37%)	0.81	1.22
Rin	113.54±1.04	115.68±1.57 (+6.52%)	120.94±1.06 (+1.88%)	115.21±1.32 (+1.47%)	0.71	1.08
Wheel	113.54±1.04	114.80±0.96 (+1.11%)	122.19±1.10 (+7.62%)	117.09±1.04 (+3.12%)	0.15	0.23

Mean ± SD, within parenthesis-per cent variation over the control

followed by type-B. Only fewer detergent cakes showed type-C response.

The *Lemna minor* treated with detergent powders showed predominantly type-B and type-C pattern followed by type-A growth response as observed on treatment with only seven detergent powders. Treatment of *Spirodela polyrrhiza* with most of the detergent powders showed predominantly type-A and B pattern. It is inferred from the growth pattern that most of the detergents whether in the form of cake or powder promoted the growth exponentially without any toxic effect up to 50 ppm concentration. Only few detergents showed toxicity to these two weeds at high concentration of 50 ppm.

12.3.2 Impact of Some Selected Detergents on Dry Weight of *Lemna minor*

Table 12.5 comprises the data on dry weight of *Lemna minor* treated in small plastic pots with varying concentrations of 12 common detergents sold in the form of cakes. Dry weight per gram of fresh plant (*Lemna minor*) significantly increased on treatments with 10 and 30 ppm of detergent as compared to the control (0 ppm). The dry weight accumulation was relatively lower at 50 ppm of all the 12 selected detergent cakes. The impact of treatment with Ariel detergent on dry weight of *Lemna minor* increased with concentration up to 30 ppm. The 30 ppm of Henko, Nirma, Rin, and Wheel detergent cakes also significantly enhance the dry weight of *Lemna minor*. The accumulation of dry weight was relatively lower in *Lemna* species treated with 50 ppm of these detergents. The impact of Budget, Doctor, Fena, 555, Ghari, Mor, and Plus detergent cakes was far lesser in comparison to the other detergents cakes studied (Table 12.5).

Table 12.6 summarizes the data on dry weight accumulation of *Lemna minor* treated with three varying doses of 24 selected detergent powders. The impact of detergent powders on dry weight of *Lemna minor* was relatively higher than the detergent cakes. Among few common brands of detergents like Ariel, Double Dog, Fena, Friendly Wash, Ghari, Henko, Mr. White, Nirma, Rin Supreme, Surf, Surf Excel, Tide, and Wheel, the impact of Surf and its new brand Surf Excel on the dry weight of *Lemna minor* was relatively higher than the other detergent powders under study. The dry weight accumulation significantly increased in *Lemna minor* on treatment with 30 ppm of Surf and its new brand Surf Excel. The other detergents like Doctor, Mor, Nirma Super, Plus and its new brand Extra Plus, and Rin Shakti had a relatively lesser degree of impact on the dry weight of *Lemna minor*. The impact of varying concentrations of less popular detergents like Cleano, Morlight, Saving Plus, and Time-Zee on the dry weight of *Lemna minor* was statistically nonsignificant (Table 12.6).

12.3.3 Impact of Some Selected Detergents on Dry Weight *Spirodela polyrrhiza*

The data on dry weight of *Spirodela polyrrhiza* treated in small plastic pots with varying concentrations of 12 selected detergent cakes are summarized in Table 12.7. There was a significant increase in the dry weight of *Spirodela polyrrhiza* on treatment with Ariel detergent cake. The dry weight of plants was significantly increased with the increase in concentration up to 30 ppm. There was relatively higher dry weight accumulation in *Spirodela polyrrhiza* treated with varying concentrations of 555, Henko, Nirma, Rin, and Wheel detergent cakes. The impact of all concentrations of Doctor, Fena, Ghari, and Mor detergent cakes on dry weight of *Spirodela polyrrhiza* was lesser than the impact of other detergents studied. Statistically there was no significant change in the dry weight of *Spirodela polyrrhiza* treated with varying concentrations of Budget and Plus detergent cakes. The high concentration (50 ppm) of Henko, Nirma, and Rin enhanced the dry weight accumulation to a noticeable extent (Table 12.7).

Table 12.6 Dry weight (mg g^{-1} of fresh weight) of *Lemna minor* treated in small plastic pots with varying doses of some common detergent powders

Detergent (Brand name)	Control	Concentration (ppm)			LSD at	
	0	10	30	50	5%	1%
Ariel	113.35 ± 1.40	118.32 ± 1.49 (+4.74%)	123.80±1.03 (+9.22%)	118.34±1.22 (+4.40%)	0.50	0.76
Cleano	113.35 ± 1.40	114.20 ± 1.34 (+0.75%)	114.71±1.11 (+1.20%)	115.45±1.31 (+1.85%)	NS	NS
Doctor	113.35 ± 1.40	114.36 ± 1.33 (+0.89%)	115.29±1.10 (+1.72%)	116.22±1.30 (+2.54%)	0.31	0.47
Double Dog	113.35 ± 1.40	122.26 ± 1.25 (+7.86%)	116.50±1.12 (+2.78%)	117.22±1.13 (+3.41%)	0.32	0.48
Fena	113.35 ± 1.40	116.35 ± 1.41 (+2.65%)	119.45±0.91 (+5.38%)	116.13±1.05 (+2.45%)	0.62	0.94
Friendly wash	113.35 ± 1.40	119.50 ± 0.87 (+5.43%)	114.75±1.16 (+1.24%)	125.31±1.66 (+10.55%)	0.84	1.27
Ghari	113.35 ± 1.40	113.40 ± 1.44 (+0.04%)	119.82±1.40 (+5.71%)	114.95±1.36 (+1.41%)	1.15	1.74
Henko	113.35 ± 1.40	116.75 ± 1.17 (+2.30%)	122.75±1.79 (+8.29%)	118.96±1.26 (+4.95%)	0.67	1.02
Max Clean	113.35 ± 1.40	113.87 ± 1.17 (+0.46%)	116.23±1.21 (+2.54%)	116.71±0.94 (+2.96%)	0.46	0.70
Mor	113.35 ± 1.40	114.52 ± 1.36 (+1.03%)	117.44±1.87 (+3.61%)	116.83±1.11 (+3.07%)	0.33	0.50
Mor light	113.35 ± 1.40	113.47 ± 1.40 (−0.2%)	115.01±1.09 (+1.47%)	114.71±1.13 (+1.20%)	NS	NS
Mr. white	113.35 ± 1.40	121.73 ± 1.04 (+7.39%)	117.35±0.93 (+3.53%)	115.10±1.12 (+1.54%)	0.49	0.74
Nirma	113.35 ± 1.40	115.22 ± 0.42 (+1.65%)	120.82 ± 1.17 (+6.59%)	115.00 ± 1.91 (+1.46%)	1.03	1.56
Nirma (Super) [a](Super Nirma)	113.35 ± 1.40	120.52 ± 0.73 (+6.33%)	113.87 ± 0.90 (+0.46%)	115.03 ± 0.99 (+1.48%)	0.69	1.04
Plus	113.35 ± 1.40	116.73 ± 1.08 (+2.98%)	115.58 ± 0.98 (+1.97%)	113.49 ± 1.28 (+0.12%)	0.46	0.70
Plus (Extra) [a](Extra Plus)	113.35 ± 1.40	115.88 ± 1.05 (+2.23%)	117.16 ± 1.13 (+3.36%)	115.59 ± 1.04 (+1.98%)	0.41	0.62
Plus (saving) [a](Saving Plus)	113.35 ± 1.40	114.94 ± 1.03 (+1.40%)	119.76 ± 1.13 (+5.66%)	117.00 ± 0.85 (+3.31%)	NS	NS
Rin Shakti	113.35 ± 1.40	116.42 ± 1.58 (+2.69%)	115.70 ± 1.13 (+2.07%)	113.58 ± 1.70 (+0.20%)	0.93	1.40
Rin Supreme	113.35 ± 1.40	125.32 ± 1.27 (+10.96%)	118.90 ± 1.12 (+4.90%)	116.48 ± 1.05 (+2.76%)	0.38	0.57
Surf	113.35 ± 1.40	117.16 ± 1.24 (+3.36%)	126.37 ± 1.29 (+11.49%)	114.25 ± 1.59 (+0.8%)	0.90	1.36
Surf Excel	113.35 ± 1.40	119.81 ± 1.12 (+5.70%)	126.43 ± 1.20 (+11.54%)	115.06 ± 0.96 (+1.51%)	0.45	0.68
Tide	113.35 ± 1.40	121.07 ± 1.16 (+6.81%)	116.08 ± 1.07 (+2.41%)	113.76 ± 1.17 (+0.37%)	1.33	2.01
Time-Zee	113.35 ± 1.40	117.09 ± 1.01 (+3.30%)	114.56 ± 1.09 (+1.07%)	114.94 ± 1.33 (+1.41%)	NS	NS
Wheel	113.35 ± 1.40	115.52 ± 1.47 (+1.91%)	121.82 ± 0.89 (+7.47%)	113.58 ± 0.96 (+0.20%)	0.73	1.10

Mean ± SD, with in parenthesis-per cent variation over the control
[a] Actual brand name

Table 12.7 Dry weight (mg/g of fresh weight) of *Spirodela polyrrhiza* treated in small plastic pots with varying doses of 12 selected detergent cakes

Detergent (Brand name)	Control	Concentration (ppm)			LSD at	
	0	10	30	50	5%	1%
Ariel	113.75 ± 1.16	117.91 ± 2.01 (+3.66%)	121.96 ± 2.07 (+7.22%)	119.56 ± 1.40 (+5.11%)	4.49	6.81
Budget	113.75 ± 1.16	117.99 ± 1.97 (+3.72%)	115.77 ± 1.56 (+1.76%)	113.80 ± 1.18 (+0.04%)	NS	NS
Doctor	113.75 ± 1.16	117.80 ± 1.32 (+3.56%)	118.92 ± 0.97 (+4.55%)	116.50 ± 1.50 (+2.42%)	2.84	4.29
Fena	113.75 ± 1.16	121.68 ± 1.98 (+6.97%)	117.57 ± 1.58 (+3.36%)	115.50 ± 1.73 (+1.54%)	4.60	6.95
555	113.75 ± 1.16	116.58 ± 2.02 (+2.49%)	121.66 ± 1.18 (+6.95%)	118.86 ± 0.91 (+4.49%)	3.82	5.79
Ghari	113.75 ± 1.16	114.88 ± 1.19 (+0.99%)	118.32 ± 1.12 (+4.02%)	116.54 ± 0.88 (+2.45%)	2.71	4.10
Henko	113.75 ± 1.16	117.67 ± 1.57 (+3.45%)	119.22 ± 1.12 (+4.81%)	123.55 ± 1.24 (+8.62%)	2.68	4.06
Mor	113.75 ± 1.16	114.80 ± 0.97 (+0.09)	118.60 ± 1.47 (+4.26%)	116.80 ± 1.28 (+2.68%)	3.16	4.80
Nirma	113.75 ± 1.16	116.58 ± 1.76 (+2.49%)	121.66 ± 1.76 (+6.95%)	118.86 ± 1.21 (+4.49%)	3.16	4.78
Plus	113.75 ± 1.16	115.50 ± 1.05 (+1.54%)	116.77 ± 1.76 (+2.65%)	119.68 ± 2.10 (+5.93%)	NS	NS
Rin	113.75 ± 1.16	118.93 ± 2.02 (+4.55%)	120.86 ± 1.98 (+6.25%)	124.19 ± 1.46 (+9.19%)	4.40	6.67
Wheel	113.75 ± 1.16	118.53 ± 1.69 (+4.20%)	123.86 ± 1.41 (+8.89%)	120.76 ± 2.07 (+6.16%)	4.50	6.82

Mea ± SD, with in parenthesis percent variation over the control

Table 12.8 comprises the data on dry weight of *Spirodela polyrrhiza* treated in small plastic pots with varying concentrations of 24 selected detergent powders. A glance on the Table 12.8 revealed that the impact of detergent powders on dry weight of *Spirodela polyrrhiza* was higher than the impact of all 12 selected detergent cakes. The *Spirodela polyrrhiza* treated with Ariel detergent powder showed maximum dry weight accumulation at 30 ppm as compared to the control (0 ppm). The impact of Double Dog detergent powder on dry weight was far lesser than the impact of Ariel. The high concentration (50 ppm) of the detergents like Fena, Ghari, Nirma, Nirma Super, and Rin Supreme significantly

Table 12.8 Dry weight (mg/g of fresh weight) of *Spirodela polyrrhiza* treated in small plastic pots with varying doses of 24 selected detergent powders

Detergent (Brand name)	Control	Concentration (ppm)			LSD at	
	0	10	30	50	5%	1%
Ariel	113.45±1.83	119.74±1.80 (+5.54%)	124.82±2.21 (+10.02%)	121.36±2.38 (+6.97%)	5.85	8.86
Cleano	113.45±1.83	117.67±2.20 (+3.72%)	116.95±2.05 (+3.09%)	114.72±1.20 (+1.12%)	NS	NS
Doctor	113.45±1.83	114.98±1.33 (+1.35%)	115.95±2.11 (+2.20%)	117.93±1.27 (+3.95%)	NS	NS
Double Dog	113.45±1.83	125.83±1.94 (+10.91%)	122.20±1.71 (+7.71%)	120.79±1.90 (+6.47%)	5.21	7.89
Fena	113.45±1.83	115.50±1.51 (+1.81%)	117.57±1.87 (+3.63%)	121.68±1.98 (+7.25%)	5.10	7.72
Friendly wash	113.45±1.83	125.38±1.59 (+10.52%)	122.96±2.31 (+8.38%)	120.54±2.33 (+6.25%)	5.76	8.73
Ghari	113.45±1.83	117.08±1.89 (+3.20%)	118.13±2.19 (+4.13%)	123.50±1.92 (+8.86%)	5.54	8.39
Henko	113.45±1.83	119.99±2.09 (+5.76%)	125.98±2.11 (+11.04%)	122.20±2.40 (+7.71%)	5.97	9.04
Max Clean	113.45±1.83	114.68±1.71 (+1.08%)	117.52±2.26 (+3.59%)	114.21±1.71 (+0.67%)	NS	NS
Mor	113.45±1.83	117.73±1.80 (+3.77%)	121.12±1.83 (+6.76%)	115.25±2.19 (+1.59%)	NS	NS
Mor light	113.45±1.83	116.81±1.76 (+2.96%)	118.59±2.32 (+4.53%)	115.14±2.42 (+1.49%)	NS	NS
Mr. white	113.45±1.83	125.09±2.20 (+10.26%)	120.65±2.18 (+6.35%)	120.80±2.41 (+6.49%)	6.10	9.24
Nirma	113.45±1.83	117.91±1.26 (+3.93%)	118.79±1.80 (+4.71%)	124.39±1.85 (+9.64%)	4.80	7.27
Nirma (Super) [a](Super Nirma)	113.45±1.83	115.15±1.89 (+1.50%)	120.60±1.40 (+6.30%)	124.00±2.54 (+9.30%)	5.47	8.28
Plus	113.45±1.83	115.37±1.92 (+1.69%)	115.10±2.56 (+1.45%)	120.52±2.39 (+6.23%)	NS	NS
Plus (extra) [a](extra plus)	113.45±1.83	115.84±1.40 (+2.12%)	120.42±1.80 (+6.14%)	114.06±2.52 (+0.54%)	NS	NS
Plus (saving) [a](saving plus)	113.45±1.83	115.00±2.24 (+1.37%)	122.89±2.56 (+8.32%)	117.27±2.43 (+3.37%)	6.44	9.76
Rin Shakti	113.45±1.83	119.07±2.61 (+5.0%)	124.83±2.33 (+10.03%)	119.79±2.58 (+5.59%)	6.62	10.03
Rin Supreme	113.45±1.83	122.27±2.22 (+7.77%)	122.16±2.41 (+7.68%)	125.73±2.04 (+10.82%)	5.45	8.25
Surf	113.45±1.83	117.33±1.54 (+3.42%)	126.42±2.01 (+11.43%)	122.57±2.07 (+8.04%)	5.29	8.02
Surf Excel	113.45±1.83	120.54±1.82 (+6.25%)	126.58±2.16 (+11.57%)	122.96±1.23 (+8.38%)	5.02	7.60
Tide	113.45±1.83	119.65±1.89 (+5.46%)	124.64±1.96 (+9.86%)	116.50±2.14 (+2.69%)	5.53	8.38
Time-Zee	113.45±1.83	114.87±2.13 (+1.25%)	115.56±1.83 (+1.86%)	119.45±1.85 (+5.29%)	NS	NS
Wheel	113.45±1.83	121.35±1.67 (+6.96%)	117.26±2.21 (+3.36%)	114.85±2.11 (+1.23%)	NS	NS

Mean±SD, within parenthesis percent variation over the control
[a] Actual brand name

enhanced the dry weight of *Spirodela polyrrhiza* as compared to 0, 10, and 30 ppm. The dry weight of *Spirodela polyrrhiza* increased significantly on treatment with 30 ppm of Friendly Wash, Henko, Saving Plus, Rin Shakti, Surf, and its new brand Surf Excel powder. The impact of Surf and Surf Excel was highest than the other detergents powder under study. The dry weight of *Spirodela polyrrhiza* statistically did not vary on treatment with varying concentrations of Cleano, Doctor, Maxclean, Mor, Morlight, Plus, Plus Extra, Time-zee, and Wheel detergent powders (Table 12.8).

12.3.4 Duckweed Response to Surf Excel Detergent in 15 L Earthen Pots

12.3.4.1 Growth Responses of *Lemna minor*

Table 12.9 comprises the data on the growth responses of *Lemna minor* treated with varying concentrations of Surf Excel in large earthen pots and studied at11th day. The statistical analysis of the data revealed that the dry weight per gram fresh plant of *Lemna minor* significantly increased on treatment with 20, 30, 40, and 50 ppm of Surf Excel. The lower concentrations of Surf Excel increased chlorophyll *a* and *b*. The nitrogen content in the plants treated with varying concentrations of Surf Excel had for greater amount of nitrogen than the control. There was a marginal but significant increase in phosphorus uptake in *Lemna minor* treated with varying concentrations of Surf Excel as compared to control plant. The phosphorus uptake was, however, highest at 20 ppm of Surf Excel. A significant increase in potassium uptake was recorded at higher concentrations of Surf Excel. Nitrogen uptake in plant increased up to 30 ppm concentration level and declined with further increase in the concentration of the detergent (Table 12.9).

12.3.4.2 Water Quality

The data on the physico–chemical properties of water samples of earthen pots studied at 11th-day stage are summarized in Table 12.10.The data show that the pH and turbidity consistently increased with the concentration in earthen pots. The dissolved oxygen (except some variations at 40 ppm level) reduced with the increase in concentration of Surf Excel. The nitrate contents decreased marginally with the increase in Surf Excel concentration. Despite significant uptake, the high amounts of phosphates (in proportion to concentration of detergent) accumulated in the solutions of Surf

Table 12.9 Growth response of *Lemna minor* treated in large earthen pots with varying concentrations of Surf Excel detergent

Parameters	Concentration (ppm)						LSD at	
	0	10	20	30	40	50	5%	1%
Dry weight (mg/g)	117.2±2.6	119.2±2.1 (+1.7%)	128.1±2.2 (+9.3%)	124.1±1.4 (+5.9%)	122.7±1.3 (+4.7%)	122.0±2.0 (+4.1%)	3.0	4.6
Chlorophyll-a (mg/g)	0.61±0.04	0.66±0.03 (+7.3%)	0.74±0.05 (+19.8%)	0.62±0.04 (+1.1%)	0.68±0.05 (+10.1%)	0.64±0.08 (+4.6%)	0.04	0.07
Chlorophyll-b (mg/g)	0.32±0.05	0.36±0.02 (+11.2%)	0.41±0.08 (+28.0%)	0.33±0.03 (+2.5%)	0.37±0.04 (+15.3%)	0.34±0.03 (+4.7%)	0.05	0.08
Chlorophyll total (mg/g)	1.00±0.04	1.07±0.07 (+6.3%)	1.19±0.09 (+18.1%)	1.04±0.07 (+3.6%)	1.07±0.06 (+6.1%)	1.07±0.07 (+6.3%)	0.06	0.09
Nitrogen (mg/100 mg)	2.68±0.22	3.18±0.19 (+18.7%)	3.39±0.19 (+26.4%)	3.65±0.25 (+36.2%)	3.22±0.24 (+20.2%)	2.96±0.29 (+10.5%)	0.28	0.56
Phosphorus (mg/100 mg)	0.30±0.04	0.38±0.05 (+27.0%)	0.41±0.02 (+37.3%)	0.39±0.04 (+28.6%)	0.37±0.03 (+24.0%)	0.37±0.04 (+22.6%)	0.02	0.05
Potassium (mg/100 mg)	1.73±0.28	1.86±0.28 (+7.5%)	1.76±0.38 (+1.7%)	1.90±0.32 (+9.8%)	2.3±0.33 (+33.0%)	2.10±0.41 (+21.4%)	0.26	0.46

Mean ± SD, within parenthesis percent increase over the control (in rounded figures)

Table 12.10 Physico–chemical characteristics of varying concentrations of Surf Excel detergent solutions including control as estimated after the experiments with *Lemna minor* 15 L earthen pots

Parameters	Concentration (ppm)						LSD at	
	0	10	20	30	40	50	5%	1%
Turbidity (NTU)	9±2	11±3 (+22.22%)	14±2 (+55.56%)	16±2 (+77.78%)	18±2 (+100%)	19±3 (+111.11%)	3.2	4.6
pH	7.6±0.1	7.7±0.1 (+1.32%)	7.9±0.2 (+3.95%)	8.1±0.1 (+6.58%)	8.5±0.2 (+11.84%)	8.8±0.2 (+15.79%)	0.3	0.4
Dissolved oxygen (mg L^{-1})	7.45±0.45	7.12±0.27 (−4.43%)	6.83±0.28 (−8.32%)	5.69±0.41 (−23.62%)	6.09±0.26 (−18.26%)	5.45±0.30 (−26.85%)	0.17	0.24
Nitrates (mg L^{-1})	±.423±0.022	0.407±0.062 (−3.75%)	0.399±0.050 (−5.60%)	0.38±0.068 (−9.69%)	0.404±0.085 (−4.49%)	0.416±0.040 (−1.42%)	0.016	0.022
Phosphates (mg L^{-1})	±.618±0.106	0.932±0.115 (+50.81%)	1.198±0.299 (+93.85%)	1.498±0.320 (+142.39%)	1.814±0.340 (+193.53%)	2.083±0.279 (+237.06%)	0.157	0.216
Potassium (mg L^{-1})	13.60±1.10	13.15±1.11 (−3.31%)	13.09±1.20 (−3.75%)	13.16±1.15 (−3.24%)	13.06±1.02 (−3.97%)	13.26±1.10 (−2.50%)	0.957	1.379

Mean ± SD, within parenthesis percent variation over the control

Excel. There was no statistical difference in potassium level in all treatments including control (Table 12.10).

12.3.4.3 Growth Responses of *Spirodela polyrrhiza*

Table 12.11 shows the data on the growth responses of *Spirodela polyrrhiza*treated in large earthen pots with varying concentrations of Surf Excel powder. As evident from data the *Spirodela polyrrhiza* grown in varying concentrations of Surf Excel accumulated larger amount of dry matter as compared to the control. The chlorophyll *a* and *b* in the plants treated with Surf Excel was marginally higher. The chlorophyll *a* and *b* in plant treated with 40 ppm of Surf Excel was relatively higher than in any other treatment. The nitrogen, phosphorus, and potash uptake was found related with concentrations of Surf Excel up to 40 ppm. The uptake of NPK showed consistent increase with the detergent concentration up to 40 ppm with some exception of nitrogen uptake (Table 12.11).

12.3.4.4 Water Quality

The data summarized in Table 12.12 show the physico–chemical properties of the water sampled from varying concentrations of Surf Excel. The turbidity and pH increased with the concentration of the detergent used. The dissolved oxygen was negatively related with the detergent concentration. After the treatment, the nitrate content in solution with higher detergent concentrations significantly reduced as compared to control. The phosphate was found almost directly related with the concentration of Surf Excel. Potassium, however, did not show any statistical difference in all water samples ranging from 0 to 50 ppm of Surf Excel (Table 12.12).

Table 12.11 Growth response of *Spirodela polyrrhiza* treated in large earthen pots with varying concentrations of Surf Excel detergent powder

Parameters	Concentration (ppm)						LSD at	
	0	10	20	30	40	50	5%	1%
Dry weight (mg/g)	122.3±1.8	125.9±1.3 (+2.9%)	124.2±2.2 (+1.6%)	125.0±2.4 (+2.2%)	131.5±2.1 (+7.5%)	127.6±2.1 (+4.3%)	2.9	4.2
Chlorophyll-a (mg/g)	0.63±0.25	0.64±0.23 (+0.8%)	0.64±0.28 (+1.4%)	0.70±0.02 (+11.2%)	0.79±0.01 (+24.2%)	0.72±0.2 (+13.9%)	0.03	0.04
Chlorophyll-b (mg/g)	0.35±0.01	0.37±0.02 (+4.0%)	0.36±0.02 (+3.0%)	0.38±0.02 (+8.3%)	0.44±0.02 (+25.9%)	0.39±0.02 (+12.0%)	0.02	0.05
Chlorophyll total (mg/g)	0.99±0.02	1.03±0.02 (+3.9%)	1.02±0.05 (+2.9%)	1.12±0.04 (+13.1%)	1.30±0.04 (+31.0%)	1.12±0.01 (+12.18%)	0.05	0.07
Nitrogen (mg/100 mg)	3.09±0.15	3.39±0.18 (+9.7%)	4.13±0.19 (+33.7%)	3.69±0.20 (+19.4%)	3.64±0.20 (+17.8%)	3.80±0.17 (+23.0%)	0.13	0.25
Phosphorus (mg/100 mg)	0.25±0.03	0.34±0.02 (+36.7%)	0.37±0.02 (+45.8%)	0.39±0.02 (+53.4%)	0.40±0.27 (+59.8%)	0.35±0.22 (+39.4%)	0.01	0.03
Potassium (mg/100 mg)	2.20±0.18	2.24±0.15 (+1.8%)	2.33±0.28 (+5.9%)	2.37±0.17 (+7.7%)	2.70±0.22 (+22.7%)	2.40±0.13 (+9.1%)	0.16	0.23

Mean ± SD, within parenthesis percent increase over the control (in rounded figures)

Table 12.12 Physico–chemical characteristics of varying concentrations of Surf Excel detergent including control as estimated after the experiments with *Spirodela polyrrhiza* in 15 L earthen pots

Parameters	Concentration (ppm)						LSD at	
	0	10	20	30	40	50	5%	1%
Turbidity (NTU)	12±2.0	14±3.6 (+16.7%)	16±4.4 (+33.3%)	19±0.0 (+28.3%)	21±2.5 (+75.0%)	22±3.0 (+83.3%)	5.17	7.35
pH	7.5±0.3	7.7±0.4 (+2.67%)	7.8±0.3 (+4.0%)	8.0±0.4 (+6.67%)	8.3±0.2 (+10.66%)	8.5±0.3 (+13.33%)	0.4	0.6
Dissolved oxygen (mg L^{-1})	7.52±0.08	7.22±0.15 (−3.99%)	6.62±0.32 (−11.97%)	6.38±0.13 (−15.14%)	5.93±0.25 (−21.11%)	5.79±0.41 (−23.03%)	0.19	0.28
Nitrates (mg L^{-1})	±0.465±0.033	0.435±0.048 (−6.45%)	0.349±0.040 (−24.95%)	0.396±0.064 (−14.84%)	0.379±0.63 (-18.49%)	0.404±0.076 (−13.12%)	0.045	0.061
Phosphates (mg L^{-1})	±0.597±0.036	0.899±0.067 (+50.59%)	1.455±0.083 (+143.72%)	1.550±0.146 (+160.00%)	1.786±0.176 (+199.16%)	2.065±0.222 (+245.90%)	0.147	0.210
Potassium (mg L^{-1})	13.22±0.41	13.15±0.41 (−0.53%)	13.12±1.00 (−0.76%)	13.0±0.16 (−1.66%)	13.12±0.21 (−0.76%)	13.21±0.20 (−0.08%)	NS	NS

Mean±SD, within parenthesis percent variation over the control

12.3.5 Effect of Temperature

12.3.5.1 Sensitivity of *Lemna minor*

The data on dry weight, chlorophyll content and NPK of *Lemna minor* recorded at 11th day of treatment or after their death (at an early stage in response to high temperatures) are summarized in Table 12.13. The greater quantity of matter accumulation was noted on treatment with 30 and 40 ppm of Surf Excel at 20 and 30 °C temperatures. The nitrogen accumulation was optimum at 30 °C in the plants treated with 30 and 40 ppm of Surf Excel. The optimum uptake of phosphorus was noted on treatment with 50 ppm of Surf Excel at 20 °C temperature. The most noticeable changes in phosphorus uptake were recorded in almost all treatments maintained at 20 and 30 °C temperatures. The potassium uptake was also significantly higher in most of the treatments at 20, 30, and 40 °C. The optimum uptake in potassium was recorded in plants treated with 40 ppm of Surf Excel at 20 °C temperature (Table 12.13).

12.3.5.2 Water Quality

The data summarized in the Table 12.14 show the physico–chemical characteristics of the water samples with varying concentrations of Surf Excel maintained at five temperature ranges and studied at 11th day of growth experiments with of *Lemna minor*. The pH and turbidity of water shows marginal but consistent increase with the detergent concentration at all temperature regimes. The dissolved oxygen reduced significantly in almost all treatments of Surf Excel with respect to control at 20 and 30 °C temperature. No significant difference in accumulation of nitrates was recorded between all the treatments. The interaction of temperature and treatment also did not show any statistical difference. The phosphates

Table 12.13 Growth response of *Lemna minor* treated in small plastic pots with varying concentrations of Surf Excel at varying temperatures

Parameters	Temperature (°C)	Concentration (ppm)						LSD at 5%
		0	10	20	30	40	50	
Dry weight (mg/g)	10	117.05±1.25	119.98±1.78 (+2.50%)	117.65±2.65 (+0.51%)	118.65±3.15 (+1.37%)	121.15±1.55 (+3.50%)	120.31±2.84 (+2.79%)	
	20	115.31±2.36	115.48±1.69 (+0.15%)	123.45±2.45 (+7.06%)	122.35±2.48 (+6.11%)	125.15±2.25 (+8.54%)	121.35±2.84 (+5.24%)	Treatment=1.89
	30	119.25±1.90	121.65±1.19 (+2.01%)	120.25±1.95 (+0.84%)	124.55±3.65 (+4.44%)	129.15±3.25 (+8.30%)	119.43±3.09 (+0.15%)	Temperature=1.72
	40[a]	92.27±2.67	91.23±2.48 (−1.12%)	93.97±3.20 (+1.84%)	92.33±1.53 (+0.65%)	95.99±3.32 (+4.01%)	93.13±2.38 (+0.93%)	Interaction=4.22
	50[b]	76.15±2.20	75.35±2.80 (−1.05%)	76.55±1.69 (+0.53%)	77.15±2.62 (+1.27%)	76.92±3.62 (+1.01%)	77.36±1.56 (+1.59%)	
Chlorophyll-a (mg/g)	10	0.563±0.012	0.610±0.022 (+8.35%)	0.575±0.014 (+2.13%)	0.653±0.025 (+15.99%)	0.621±0.020 (+10.30%)	0.582±0.023 (+3.37%)	
	20	0.586±0.021	0.649±0.028 (+10.75%)	0604±0.029 (+6.34%)	0.722±0.021 (+27.11%)	0.658±0.025 (+15.84%)	0.632±0.022 (+11.27%)	Treatment=0.023
	30	0.572±0.013	0.675±0.016 (+18.01%)	0.622±0.021 (+8.74%)	0.699±0.022 (+22.20%)	0.689±0.024 (+20.45%)	0.608±0.024 (+6.29%)	Temperature=0.015
	40[a]	0.482±0.016	0.448±0.019 (+7.05%)	0.505±0.016 (+4.77%)	0.491±0.032 (+1.87%)	0.484±0.020 (+0.41%)	0.487±0.024 (+1.04%)	Interaction=0.038
	50[b]	0.436±0.017	0.449±0.024 (+14.44%)	0.445±0.018 (+2.06%)	0.454±0.023 (+4.13%)	0.515±0.025 (+18.12%)	0.440±0.032 (+0.92%)	
Chlorophyll-b (mg/g)	10	0.233±0.027	0.254±0.023 (+9.01%)	0.237±0.043 (+1.72%)	0.275±0.026 (+18.03%)	0.262±0.023 (+12.45%)	0.248±0.023 (+6.44%)	
	20	0.254±0.019	0.355±0.017 (+39.76%)	0.268±0.023 (+5.51%)	0.370±0.020 (+45.67%)	0.317±0.022 (+24.80%)	0.271±0.026 (+6.69%)	Treatment=0.017
	30	0.275±0.019	0.307±0.032 (+11.64%)	0.305±0.022 (+10.91%)	0.417±0.028 (+51.64%)	0.360±0.012 (+30.90%)	0.321±0.020 (+16.73%)	Temperature=0.015
	40[a]	0.169±0.024	0.185±0.015 (+9.46%)	0.177±0.017 (+4.73%)	0.175±0.028 (+3.55%)	0.181±0.030 (+7.10%)	0.172±0.023 (+1.78%)	Interaction=0.038
	50[b]	0.189±0.018	0.176±0.022 (−7.41%)	0.173±0.014 (−8.47%)	0.192±0.021 (+1.59%)	0.177±0.019 (−6.35%)	0.199±0.030 (+5.29%)	
Total chlorophyll (mg/g)	10	0.844±0.023	0.916±0.101 (+8.53%)	0.890±0.056 (+5.45%)	1.034±0.034 (+22.51%)	0.888±0.027 (+5.21%)	0.870±0.130 (+3.08%)	
	20	0.874±0.021	1.064±0.050 (+8.53%)	0.931±0.036 (+6.52%)	1.208±0.103 (+38.22%)	1.027±0.034 (+17.51%)	0.905±0.025 (+3.55%)	Treatment=0.045
	30	0.909±0.028	1.022±0.033 (+12.43%)	0.973±0.028 (+7.04%)	1.168±0.089 (+28.49%)	1.071±0.086 (+17.82%)	0.945±0.138 (+3.96%)	Temperature=0.041
	40[a]	0.632±0.023	0.719±0.042 (+13.76%)	0.652±0.027 (+3.16%)	0.688±0.057 (+8.86%)	0.679±0.046 (+7.44%)	0.673±0.012 (+6.49%)	Interaction=0.100
	50[b]	0.507±0.034	0.526±0.037 (+3.74%)	0.516±0.037 (+1.78%)	0.527±0.038 (+3.94%)	0.538±0.039 (+6.11%)	0.514±0.024 (+1.38%)	
Nitrogen (mg/100 mg)	10	2.70±0.31	2.88±0.56 (+6.73%)	3.10±0.25 (+14.58%)	3.03±0.28 (+12.13%)	2.92±0.48 (+7.92%)	2.86±0.44 (+5.95%)	
	20	2.89±0.45	2.74±0.31 (+5.33%)	2.95±0.51 (+1.94%)	3.42±0.49 (+18.26%)	3.18±0.43 (+9.82%)	2.90±0.58 (+0.21%)	Treatment=NS
	30	3.08±0.19	3.33±0.24 (+7.92%)	3.25±0.21 (+5.32%)	3.71±0.74 (+20.38%)	3.44±0.33 (+11.49%)	3.25±0.45 (+5.52%)	Temperature=0.28
	40[a]	2.31±0.21	2.64±0.44 (+14.40%)	2.39±0.39 (+3.56%)	2.51±0.36 (+8.85%)	2.46±0.47 (+6.59%)	2.53±0.30 (+9.80%)	Interaction=0.67
	50[b]	2.04±0.15	2.01±0.06 (−1.67%)	2.04±0.40 (+0.05%)	2.12±0.37 (+3.82%)	2.03±0.50 (−0.69%)	2.03±0.14 (−0.54%)	
Phosphorus (mg/100 mg)	10	0.215±0.027	0.219±0.039 (+1.86%)	0.215±0.015 (+0.0%)	0.232±0.043 (+7.91%)	0.224±0.016 (+4.19%)	0.288±0.031 (+6.05%)	
	20	0.231±0.030	0.260±0.023 (+12.55%)	0.274±0.021 (+18.61%)	0.304±0.023 (+31.60%)	0.289±0.014 (+25.11%)	0.324±0.023 (+40.26%)	Treatment=NS
	30	0.257±0.017	0.298±0.051 (+15.95%)	0.238±0.029 (+7.39%)	0.355±0.027 (+38.13%)	0.338±0.035 (+31.52%)	0.280±0.045 (+8.95%)	Temperature=0.020
	40[a]	0.207±0.022	0.228±0.018 (+10.14%)	0.217±0.028 (+4.83%)	0.244±0.027 (+17.87%)	0.254±0.026 (+22.20%)	0.217±0.032 (+4.83%)	Interaction=0.044
	50[b]	0.177±0.032	0.186±0.080 (+5.08%)	0.181±0.022 (+2.26%)	0.200±0.027 (+12.99%)	0.196±0.029 (+10.73%)	0.191±0.020 (+7.91%)	
Potassium (mg/100 mg)	10	1.50±0.38	1.56±0.16 (+4.02%)	1.58±0.19 (+5.78%)	1.52±0.260 (+1.54%)	1.56±0.21 (+4.21%)	1.74±0.25 (+16.44%)	
	20	1.85±0.17	2.02±0.21 (+9.44%)	2.06±0.28 (+11.53%)	1.85±0.27 (+0.22%)	2.23±0.23 (+20.84%)	1.86±0.12 (+0.65%)	Treatment=NS
	30	1.70±0.19	1.60±0.31 (+6.22%)	1.85±0.21 (+8.57%)	1.97±0.20 (+15.55%)	2.00±0.19 (+17.37%)	1.98±0.30 (+16.37%)	Temperature=0.14
	40[a]	1.21±0.16	1.23±0.12 (+1.82%)	1.42±0.31 (+17.58%)	1.28±0.18 (+6.22%)	1.32±0.23 (+9.78%)	1.54±0.20 (+27.86%)	Interaction=0.35
	50[b]	1.04±0.05	1.04±0.05 (+0.30%)	1.06±0.07 (+1.83%)	1.11±0.10 (+6.24%)	1.08±0.09 (+3.75%)	1.07±0.09 (+2.52%)	

Mean±SD, with in parenthesis percent variation over the control

[a] Studied in samples collected at seventh day after the death of plants

[b] Studied in samples collected at fifth day after the death of plant

Table 12.14 Physico–chemical characteristics of water containing varying concentration of surf excel detergent maintained at varying temperature studied after 11th day of growth of *Lemna minor*

Parameters	Temperature (°C)	Concentration (ppm) 0	10	20	30	40	50	LSD at 5%
Turbidity (NTU)	10	10±1	11±1 (+10%)	13±1 (+30%)	14±1 (+40%)	15±3 (+50%)	16±1 (+60%)	
	20	11±2	12±1 (+9.09%)	12±2 (+9.09%)	15±1 (+36.36%)	16±2 (+45.45%)	17±2 (+55.55%)	Treatment = 1.74
	30	13±2	14±2 (+7.69%)	16±1 (+23.17%)	18±2 (+46.15%)	20.0±3 (+53.85%)	22±1 (+69.23%)	Temperature = 1.58
	40[a]	15±2	17±1 (+13.33%)	19±3 (+26.67%)	19±3 (+26.67%)	21±4 (+40.0%)	22±1 (+46.66%)	Interaction = 3.88
	50[b]	17±3	18±2 (+5.88%)	20.0±4 (+17.64%)	21±2 (+23.53%)	21±1 (+23.53%)	23±5 (+35.29%)	
pH	10	7.4±0.3	7.5±0.4 (+1.35%)	7.7±0.3 (+4.05%)	7.9±0.3 (+6.76%)	8.0±0.3 (+8.11%)	8.2±0.2 (+10.81%)	
	20	7.5±0.3	7.7±0.3 (+2.67%)	7.8±0.4 (+4.0%)	8.1±0.2 (+8.00%)	8.3±0.1 (+10.67%)	8.4±0.1 (+12.0%)	Treatment = 0.22
	30	7.5±0.4	7.6±0.2 (+1.33%)	7.8±0.4 (+4.0%)	8.2±0.1 (+9.33%)	8.4±0.3 (+12.0%)	8.5±0.5 (+13.33%)	Temperature = 0.20
	40[a]	7.7±0.2	7.9±0.4 (+2.60%)	8.2±0.3 (+6.49%)	8.3±0.2 (+7.79%)	8.5±0.2 (+10.39%)	8.7±0.2 (+12.99%)	Interaction = 0.49
	50[b]	7.6±0.3	7.8±0.4 (+2.63%)	8.1±0.4 (+6.58%)	8.3±0.1 (+11.84%)	8.5±0.11 (+11.84%)	8.6±0.4 (+13.15%)	
Dissolved oxygen (mg L^{-1})	10	7.47±0.32	6.76±0.21 (−9.50%)	7.03±0.22 (−5.89%)	6.52±0.34 (−12.72%)	6.65±0.24 (−10.98%)	6.49±0.18 (−13.12%)	
	20	7.90±0.11	7.50±0.40 (−5.06%)	6.78±0.16 (−14.18%)	6.65±0.25 (−15.82%)	5.08±0.24 (−39.70%)	6.00±0.10 (−24.05%)	Treatment = 0.19
	30	7.33±0.35	6.47±0.22 (−11.73%)	6.95±0.15 (−5.18%)	5.70±0.16 (−22.24%)	5.18±0.27 (−29.33%)	5.47±0.17 (−25.40%)	Temperature = 0.17
	40[a]	7.07±0.22	6.31±0.12 (−10.75%)	7.35±0.25 (−3.96%)	6.98±0.26 (−1.27%)	6.73±0.22 (−4.81%)	6.55±0.34 (−7.35%)	Interaction = 0.42
	50[b]	7.60±0.15	6.87±0.15 (−9.61%)	7.43±0.23 (−2.24%)	7.22±0.37 (−5.0%)	7.21±0.34 (−5.13%)	7.06±0.26 (−7.11%)	
Nitrates (mg L^{-1})	10	0.742±0.033	0.736±0.045 (−0.81%)	0.724±0.074 (−2.43%)	0.728±0.028 (−1.89%)	0.738±0.017 (−0.54%)	0.725±0.054 (−2.29%)	
	20	0.734±0.049	0.717±0.029 (−2.32%)	0.669±0.070 (−8.86%)	0.642±0.072 (−12.53%)	0.733±0.030 (−0.14%)	0.724±0.059 (−1.36%)	Treatment = NS
	30	0.703±0.028	0.653±0.044 (−7.11%)	0.613±0.035 (−12.80%)	0−685±0.065 (−2.56%)	0.683±0.028 (−2.84%)	0.669±0.080 (−4.83%)	Temperature = 0.038
	40[a]	0.723±0.030	0.695±0.145 (−3.87%)	0.715±0.051 (−1.12%)	0.705±0.028 (−2.44%)	0.742±0.028 (−2.63%)	0.705±0.035 (−2.49%)	Interaction = 0.093
	50[b]	0.749±0.023	0.741±0.076 (−1.07%)	0.693±0.088 (−7.48%)	0.740±0.038 (−1.07%)	0.739±0.018 (−1.34%)	0.740±0.05 (−1.20%)	
Phosphates (mg L^{-1})	10	0.630±0.040	1.043±0.056 (+65.56%)	1.426±0.219 (+126.35%)	1.782±0.557 (+182.86%)	2.093±0.128 (+232.22%)	2.330±0.341 (+269.84%)	
	20	0.590±0.060	1.066±0.091 (+80.68%)	1.434±0.048 (+143.05%)	1.726±0.522 (+192.54%)	2.040±0.145 (+245.76%)	2.274±0.379 (+285.42%)	Treatment = 0.211
	30	0.610±0.05	1.096±0.116 (+79.67%)	1.371±0.376 (+124.75%)	1.688±0.388 (+176.72%)	2.063±0.129 (+238.20%)	2.310±0.335 (+278.69%)	Temperature = 0.193
	40[a]	0.620±0.020	1.075±0.100 (+73.39%)	1.402±0.402 (+126.13%)	1.754±0.359 (+182.90%)	2.058±0.193 (+231.94%)	2.322±0.322 (+274.52%)	Interaction = 0.472
	50[b]	0.630±0.040	1.080±0.089 (+71.43%)	1.443±0.257 (+129.05%)	1.745±0.295 (+176.98%)	2.004±0.113 (+218.10%)	2.359±0.309 (+274.44%)	
Potassium (mg L^{-1})	10	13.69±0.49	13.52±0.83 (−1.24%)	13.39±0.59 (−2.19%)	13.56±0.74 (−0.95%)	13.41±1.26 (−2.05%)	13.55±1.10 (−1.02%)	
	20	13.54±0.53	13.52±0.83 (−0.15%)	13.34±0.38 (−2.56%)	13.52±0.52 (−1.24%)	13.42±1.23 (−1.97%)	13.22±0.41 (−1.24%)	Treatment = 0.04
	30	13.58±0.58	13.45±0.59 (−0.96%)	13.35±0.35 (−1.69%)	13.48±0.27 (−0.74%)	13.48±0.62 (−1.97%)	13.42±1.11 (−1.18%)	Temperature = NS
	40[a]	13.68±1.24	13.52±0.61 (−1.17%)	13.48±0.65 (−1.46%)	13.51±0.71 (−1.24%)	13.43±0.89 (−1.83%)	13.52±0.95 (−1.17%)	Interaction = NS
	50[b]	13.54±0.55	13.50±0.48 (−0.30%)	13.39±0.62 (−1.11%)	13.51±0.64 (−0.22%)	13.44±0.94 (−0.74%)	13.44± (−0.74%)	

Mean ± SD, with in parenthesis percent variation over the control
[a] Studied in samples collected at seventh day after the death of plants
[b] Studied in samples collected at fifth day after the death of plants

were significantly high and the quantity consistently increased with the concentration of Surf Excel. The phosphate accumulation of water was statistically found directly related with temperature. With one exception there was no statistical difference in potassium accumulation in all treatments including control. Similarly temperature also did not affect the potassium content of the solution. It was noticeable that the *Lemna minor* had high mortality in higher concentration and temperature levels (Table 12.14).

12.3.5.3 Sensitivity of *Spirodela polyrrhiza*

The data summarized in Table 12.15 show the growth response of *Spirodela polyrrhiza* treated in small pots with varying concentration of Surf Excel at varying temperatures. The dry weight accumulation significantly decreased in *Spirodela polyrrhiza* maintained at 40 and 50 °C in all treatments levels. The dry weight accumulation of *Spirodela polyrrhiza* was, however, statistically similar in all concentrations maintained at 10, 20, and 30 °C. Significant reductions in dry weight and chlorophyll content were noted in all treatments maintained at 40 and 50 °C temperature (as recorded in the samples collected either on 5th day, 9th day or after the termination of the experiment at 11th day). Nitrogen uptake was optimum in 40 ppm concentration at 20 and 30 °C. Significantly a higher amount of phosphorous uptake was recorded at 20 and 30 °C temperatures in all doses of Surf Excel. The uptake of phosphorous was also relatively higher in all concentrations of Surf Excel at 10 °C but the uptake of phosphorous did not show any significant decrease at 40 °C of temperature. The potassium uptake in lower doses showed some increase up to 40 °C temperature and in higher doses only up to 20 °C of temperature (Table 12.15).

12.3.5.4 Water Quality

The data summarized in Table 12.16 show the physico–chemical properties of the detergent solution as studied after the growth of *Spirodela polyrrhiza* at varying temperature levels. The turbidity was recorded to be significantly high in 20 ppm and higher detergent concentrations at almost all temperature levels as compared to their corresponding control. The pH of the solutions showed a consistent increase with the concentration level. The pH of the 40 and 50 ppm of the detergent solution was noted to be highest at 40 and 50 °C temperatures. The dissolved oxygen at lower temperature did not show any statistical difference between control and all concentrations of the detergent solution. However, at 20 and 30 °C, the dissolved oxygen significantly reduced in 40 and 50 ppm of Surf Excel as compared to their respective controls. At 40 and 50 °C temperatures the dissolved oxygen was statistically equal ($P > 0.05$) in all detergent concentrations including control. In Surf Excel solutions there were minor reductions in nitrates specifically at 20 and 30 °C. There was no significant difference in the potassium content in all the solutions. However, the phosphate content showed a noticeable difference. The greater phosphate content was recorded in the solutions of higher detergent concentrations. Even 10 ppm of Surf Excel solutions had significantly higher amount of phosphate as compared to control (Table 12.16).

12.3.6 Effect of pH

12.3.6.1 Sensitivity of *Lemna minor*

The data on the growth responses of *Lemna minor* treated at varying pH levels with varying concentrations of Surf Excel detergent are summarized in Table 12.17. The pH and variation in detergent concentration did not affect the dry matter accumulation of *Lemna minor*. Similarly there was no impact on chlorophyll content and potassium uptake but there was a significant increase in nitrogen and phosphorus uptake. The uptake of nitrogen and phosphorus was significantly higher at lower pH and in higher concentrations of Surf Excel. On treatment with 50 ppm of Surf Excel, the optimum nitrogen uptake was recorded at 7.0 pH. The optimum increase in phosphorus uptake was recorded at pH 6.5 and concentration level of 40 and 50 ppm (Table 12.17).

12.3.6.2 Water Quality

Table 12.18 shows the data on physico–chemical properties of the water samples studied after the growth of *Lemna minor* at varying pH and detergent concentrations. The statistical analysis revealed that there was no significant difference in turbidity, DO, nitrates, and potassium contents in water. However, in the detergent solutions there was significantly higher level of phosphates directly related with the concentration levels. But no significant difference in phosphate content was recorded at varying pH and concentration levels of the detergent (Table 12.18).

12.3.6.3 Sensitivity of *Spirodela polyrrhiza*

The data summarized in Table 12.19 shows the growth response of *Spirodela polyrrhiza* grown in varying concentrations of Surf Excel at varying pH levels. The dry matter accumulation was recorded to be higher at acidic pH (6.0–6.5 pH) in almost all detergent concentrations including the control. The chlorophyll contents in *Spirodela polyrrhiza* also increased significantly when treated with higher concentrations of Surf Excel (30–50 ppm) at lower pH (6.0 and 6.5). There was statistically no significant impact of pH on potassium uptake at each concentration levels. The uptake of potassium was, however, observed to be higher in plants grown in 30 and 50 ppm of Surf Excel at all ranges of pH. The uptake of nitrogen was mainly related with the concentrations of detergent. The nitrogen uptake was enhanced with decrease in pH and increase in the concentration level of detergent. The uptake of phosphorus was found related

Table 12.15 Growth response of *Spirodela polyrrhiza* treated in small plastic pots with varying concentrations of Surf Excel at varying temperatures

Parameters	Temp. (°C)	Concentration (ppm)						LSD at 5 %
		0	10	20	30	40	50	
Dry weight (mg/g)	10	122.80 ± 1.20	124.27 ± 1.23 (+1.2 %)	123.97 ± 0.76 (+0.95 %)	123.80 ± 2.10 (+0.81 %)	126.30 ± 0.87 (+2.85 %)	123.32 ± 2.82 (+0.42 %)	
	20	126.63 ± 1.15	127.87 ± 1.38 (+0.98 %)	128.31 ± 3.20 (+1.33 %)	127.93 ± 1.55 (+1.03 %)	129.40 ± 1.30 (+2.19 %)	127.30 ± 1.37 (+0.52 %)	Treatment = 0.82
	30	124.70 ± 1.80	126.51 ± 1.16 (+1.45 %)	126.77 ± 1.02 (+1.66 %)	126.60 ± 1.30 (+1.52 %)	132.53 ± 0.75 (+6.28 %)	124.73 ± 4.25 (+0.02 %)	Temperature = 0.75
	40[a]	96.57 ± 2.14	95.53 ± 2.25 (−1.08 %)	98.13 ± 3.89 (+1.62 %)	98.63 ± 1.27 (+2.13 %)	100.27 ± 2.84 (−3.83 %)	97.43 ± 1.15 (+0.89 %)	Interaction = 1.83
	50[b]	80.55 ± 3.15	81.77 ± 1.22 (+1.51 %)	81.36 ± 1.12 (+1.01 %)	82.35 ± 1.12 (+2.23 %)	82.11 ± 1.12 (+1.93 %)	82.73 ± 1.86 (+2.71 %)	
Chlorophyll-a (mg/g)	10	0.603 ± 0.012	0.644 ± 0.044 (+6.80 %)	0.683 ± 0.057 (+13.27 %)	0.613 ± 0.058 (+1.66 %)	0.655 ± 0.047 (+8.62 %)	0.628 ± 0.024 (+4.15 %)	
	20	0.575 ± 0.058	0.688 ± 0.060 (+19.65 %)	0.770 ± 0.069 (+33.91 %)	0.629 ± 0.055 (+9.39 %)	0.700 ± 0.038 (+21.74 %)	0.620 ± 0.038 (+7.83 %)	Treatment = 0.007
	30	0.589 ± 0.059	0.672 ± 0.040 (+14.09 %)	0.743 ± 0.040 (26.15 %)	0.637 ± 0.038 (+8.15 %)	0.680 ± 0.038 (+15.45 %)	0.647 ± 0.048 (+9.85 %)	Temperature = 0.007
	40[a]	0.519 ± 0.041	0.536 ± 0.037 (+3.28 %)	0.532 ± 0.053 (+2.50 %)	0.526 ± 0.047 (+1.35 %)	0.528 ± 0.029 (+1.73 %)	0.522 ± 0.032 (+0.06 %)	Interaction = 0.016
	50[b]	0.461 ± 0.061	0.470 ± 0.049 (+1.95 %)	0.471 ± 0.021 (+2.17 %)	0.468 ± 0.047 (+1.52 %)	0.473 ± 0.039 (+2.60 %)	0.467 ± 0.054 (+1.30 %)	
Chlorophyll-b (mg/g)	10	0.276 ± 0.050	0.299 ± 0.065 (+8.33 %)	0.316 ± 0.046 (+14.49 %)	0.286 ± 0.062 (+3.62 %)	0.286 ± 0.055 (+3.62 %)	0.297 ± 0.047 (+7.61 %)	
	20	0.275 ± 0.038	0.318 ± 0.035 (+14.91 %)	0.299 ± 0.049 (+8.73 %)	0.297 ± 0.048 (+8.0 %)	0.307 ± 0.039 (+11.64 %)	0.307 ± 0.058 (+11.64 %)	Treatment = 0.007
	30	0.302 ± 0.040	0.382 ± 0.042 (+26.49 %)	0.438 ± 0.038 (+45.00 %)	0.331 ± 0.048 (+9.60 %)	0.383 ± 0.039 (+26.82 %)	0.346 ± 0.034 (+14.56 %)	Temperature = 0.006
	40[a]	0.186 ± 0.051	0.228 ± 0.025 (+22.58 %)	0.239 ± 0.038 (+28.49 %)	0.188 ± 0.044 (+1.08 %)	0.224 ± 0.045 (+20.4 %)	0.221 ± 0.010 (+18.82 %)	Interaction = 0.015
	50[b]	0.211 ± 0.051	0.189 ± 0.050 (−10.43 %)	0.192 ± 0.044 (−9.00 %)	0.226 ± 0.050 (+7.11 %)	0.190 ± 0.030 (−9.95 %)	0.542 ± 0.028 (+1.69)	
Total chlorophyll (mg/g)	10	0.883 ± 0.011	0.927 ± 0.104 (+4.98 %)	1.191 ± 0.112 (+34.88 %)	1.020 ± 0.135 (+15.52 %)	1.023 ± 0.110 (+15.85 %)	0.906 ± 0.109 (+2.60 %)	
	20	0.928 ± 0.129	0.958 ± 0.140 (+3.23 %)	1.166 ± 0.109 (+25.65 %)	1.047 ± 0.155 (+12.82 %)	1.086 ± 0.160 (+17.03 %)	0.932 ± 0.110 (+0.43 %)	Treatment = 0.009
	30	0.903 ± 0.109	0.990 ± 0.095 (+9.63 %)	1.222 ± 0.196 (+35.32 %)	1.079 ± 0.121 (+19.49 %)	1.052 ± 0.153 (+16.50 %)	0.868 ± 0.107 (+3.88 %)	Temperature = 0.008
	40[a]	0.675 ± 0.128	0.691 ± 0.069 (+2.37 %)	0.750 ± 0.112 (+11.11 %)	0.714 ± 0.069 (+5.78 %)	0.723 ± 0.060 (+7.11 %)	0.718 ± 0.061 (+6.37 %)	Interaction = 0.021
	50[b]	0.533 ± 0.133	0.538 ± 0.130 (+0.94 %)	0.546 ± 0.041 (+2.43 %)	0.556 ± 0.097 (+4.32 %)	0.542 ± 0.028 (+1.69 %)	0.536 ± 0.027 (+0.56 %)	
Nitrogen (mg/100 mg)	10	2.73 ± 0.63	2.85 ± 0.30 (+4.50 %)	2.79 ± 0.15 (+2.35 %)	2.86 ± 0.20 (+4.76 %)	2.75 ± 0.18 (+0.73 %)	2.98 ± 0.33 (+9.15 %)	
	20	3.18 ± 0.19	3.30 ± 0.46 (+3.90 %)	3.29 ± 0.20 (+3.42 %)	3.27 ± 0.29 (+2.90 %)	3.49 ± 0.29 (+9.74 %)	2.60 ± 0.27 (+5.03 %)	Treatment = 0.17
	30	3.44 ± 0.40	3.60 ± 0.19 (+4.65 %)	3.58 ± 0.18 (+4.16 %)	3.51 ± 0.51 (+2.03 %)	3.78 ± 0.19 (+9.88 %)	3.54 ± 0.31 (+2.91 %)	Temperature = 0.16
	40[a]	2.45 ± 0.29	2.57 ± 0.35 (+4.90 %)	2.32 ± 0.30 (−5.31 %)	2.52 ± 0.20 (+2.86 %)	2.57 ± 0.35 (+4.90 %)	2.47 ± 0.29 (+0.82 %)	Interaction = 0.39
	50[b]	2.14 ± 0.20	2.10 ± 0.29 (−1.87 %)	2.06 ± 0.15 (−3.74 %)	2.13 ± 0.29 (−0.47 %)	2.18 ± 0.19 (+1.87 %)	2.10 ± 0.40 (−1.87 %)	
Phosphorus (mg/100 mg)	10	0.264 ± 0.059	0.301 ± 0.050 (+14.02 %)	0.280 ± 0.012 (+6.06 %)	0.283 ± 0.058 (+7.20 %)	0.270 ± 0.025 (+2.27 %)	0.272 ± 0.057 (+3.03 %)	
	20	2.240 ± 0.039	0.282 ± 0.038 (+17.51 %)	0.343 ± 0.026 (+42.92 %)	0.330 ± 0.028 (+37.50 %)	0.291 ± 0.039 (+21.25 %)	0.323 ± 0.024 (+34.58 %)	Treatment = 0.007
	30	0.296 ± 0.061	0.331 ± 0.031 (+11.82 %)	0.384 ± 0.029 (+29.73 %)	0.371 ± 0.041 (+25.34 %)	0.317 ± 0.050 (+7.09 %)	0.360 ± 0.040 (+21.62 %)	Temperature = 0.006
	40[a]	0.276 ± 0.049	0.256 ± 0.050 (−7.24 %)	0.272 ± 0.041 (+1.45 %)	0.293 ± 0.019 (+6.16 %)	0.247 ± 0.041 (−10.50 %)	0.268 ± 0.045 (−2.90 %)	Interaction = 0.016
	50[b]	0.214 ± 0.050	0.219 ± 0.070 (+2.34 %)	0.229 ± 0.035 (+7.01 %)	0.263 ± 0.041 (+10.28 %)	0.216 ± 0.060 (+0.93 %)	0.216 ± 0.020 (+0.93 %)	
Potassium (mg/100 mg)	10	1.47 ± 0.22	1.50 ± 0.16 (+2.04 %)	1.57 ± 0.31 (+6.80 %)	1.71 ± 0.76 (+16.33 %)	1.59 ± 0.10 (+8.16 %)	1.48 ± 0.21 (+0.08 %)	
	20	1.69 ± 0.31	1.73 ± 0.31 (+2.49 %)	1.95 ± 0.31 (+15.38 %)	2.27 ± 0.22 (+34.32 %)	1.91 ± 0.32 (+13.02 %)	1.86 ± 0.31 (+10.06 %)	Treatment = 0.037
	30	1.80 ± 0.11	1.60 ± 0.32 (+11.11 %)	2.01 ± 0.11 (+11.66 %)	2.14 ± 0.11 (+18.88 %)	2.02 ± 0.21 (+12.22 %)	1.85 ± 0.36 (+2.78 %)	Temperature = 0.034
	40[a]	1.33 ± 0.11	1.55 ± 0.19 (+16.54 %)	1.39 ± 0.33 (+4.57 %)	1.35 ± 0.11 (+1.50 %)	1.12 ± 0.22 (−15.79 %)	1.27 ± 0.11 (+4.51 %)	Interaction = 0.083
	50[b]	1.13 ± 0.31	1.11 ± 0.21 (−1.77 %)	1.19 ± 0.21 (+5.31 %)	1.16 ± 0.11 (+2.65 %)	1.02 ± 0.21 (−9.85 %)	1.10 ± 0.21 (−2.65 %)	

Mean ± SD, with in parenthesis percent variation over the control
[a] studied in samples collected at 9th day after the death of plants
[b] studied in samples collected at 5th day after the death of plant

Table 12.16 Physico-chemical characteristics of varying concentrations of Surf Excel detergent studied at 11th day after the growth of *Spirodela polyrrhiza* at varying temperature levels

Parameters	Temp. (°C)	Concentration (ppm)						LSD at 5%
		0	10	20	30	40	50	
Turbidity (NTU)	10	10±1	11±2 (+10%)	13±2 (+30%)	13±1 (+30%)	14±1 (+40%)	14±1 (+40%)	
	20	10±1	12±2 (+20%)	14±3 (+40%)	15±2 (+50%)	16±2 (+60%)	17±2 (+70%)	Treatment = 1.2
	30	12±2	13±2 (+8.3%)	15±2 (+25%)	16±2 (+25%)	18±2 (+50%)	19±2 (+58.3%)	Temperature = 1.1
	40[a]	11±2	13±1 (+18.18%)	16±2 (+45.45%)	16±1 (+45.45%)	18±2 (+63.63%)	19±2 (+72.73%)	Interaction = NS
	50[b]	12±1	14±1 (+16.67%)	17±1 (+41.67%)	18±3 (+50%)	19±3 (+58.3%)	20±3 (+66.67%)	
pH	10	7.5±0.4	7.6±0.5 (+1.33%)	7.8±0.4 (+4.0%)	8.1±0.3 (+8.0%)	8.3±0.2 (+10.67%)	8.5±0.1 (+13.33%)	
	20	7.7±0.3	7.8±0.3 (+1.29%)	8.0±0.2 (+3.90%)	8.2±0.5 (+6.49%)	8.4±0.4 (+9.09%)	8.6±0.2 (+11.69%)	Treatment = 0.11
	30	7.5±0.4	7.6±0.2 (+1.33%)	7.7±0.2 (+2.67%)	7.9±0.2 (+5.33%)	8.2±0.2 (+9.33%)	8.4±0.5 (+12.0%)	Temperature = 0.10
	40[a]	7.6±0.3	7.8±0.2 (+2.63%)	8.1±0.4 (+6.58%)	8.3±0.2 (+9.21%)	8.5±0.2 (+11.84%)	8.6±0.2 (+13.16%)	Interaction = 0.25
	50[b]	7.4±0.4	7.5±0.5 (+1.35%)	7.6±0.3 (+2.70%)	7.9±0.3 (+6.76%)	8.2±0.3 (+10.81%)	8.5±0.2 (+14.86%)	
Dissolved oxygen (mg L^{-1})	10	6.6±0.3	6.5±0.3 (−1.52%)	6.4±0.3 (−3.03%)	6.4±0.3 (−3.03%)	6.2±0.2 (−6.06%)	6.0±0.2 (−9.09%)	
	20	6.7±0.3	6.5±0.3 (−2.48%)	6.4±0.1 (−4.48%)	6.0±0.4 (−10.45%)	5.8±0.2 (−13.43%)	5.5±0.2 (−17.91%)	Treatment = 0.09
	30	6.8±0.2	6.3±0.1 (−7.35%)	6.5±0.2 (−4.41%)	5.5±0.4 (−19.12%)	5.3±0.1 (−22.05%)	5.0±0.1 (−26.47%)	Temperature = 0.08
	40[a]	7.0±0.3	6.9±0.4 (−1.43%)	6.8±0.3 (−2.86%)	6.9±0.1 (−1.43%)	6.7±0.2 (−4.29%)	6.6±0.2 (−5.71%)	Interaction = 0.19
	50[b]	7.2±0.3	7.1±0.3 (−1.39%)	7.09±0.2 (−1.49%)	7±0.1 (−2.78%)	6.81±0.2 (−5.56%)	6.7±0.3 (−6.94%)	
Nitrates (mg L^{-1})	10	0.709±0.110	0.706±0.105 (−0.42%)	0.701±0.094 (−1.13%)	0.707±0.101 (−0.28%)	0.702±0.108 (−0.99%)	0.704±0.108 (−0.71%)	
	20	0.690±0.09	0.646±0.047 (−6.38%)	0.622±0.091 (−9.86%)	0.680±0.090 (−1.45%)	0.671±0.110 (−2.75%)	0.675±0.068 (−2.17%)	Treatment = 0.017
	30	0.671±0.110	0.595±0.095 (−11.32%)	0.661±0.089 (−1.49%)	0.696±0.092 (−3.73%)	0.601±0.042 (−10.43%)	0.633±0.083 (−5.66%)	Temperature = 0.017
	40[a]	0.698±0.115	0.677±0.091 (−4.41%)	0.688±0.093 (−1.43%)	0.665±0.075 (−4.73%)	0.687±0.101 (−1.58%)	0.682±0.090 (−2.29%)	Interaction = 0.036
	50[b]	0.713±0.114	0.698±0.092 (−2.10%)	0.708±0.107 (−0.70%)	0.703±0.091 (−1.37%)	0.702±0.109 (−1.54%)	0.700±0.105 (−1.82%)	
Phosphates (mg L^{-1})	10	0.590±0.110	1.065±0.092 (+80.51%)	1.414±0.095 (+139.66%)	1.746±0.163 (+195.93%)	2.064±0.210 (+249.83%)	2.328±0.093 (+294.58%)	
	20	0.600±0.109	1.068±0.190 (+78%)	1.358±0.112 (+126.33%)	1.708±0.144 (+184.67%)	1.991±0.110 (+281.83%)	2.319±0.110 (+286.50%)	Treatment = 0.007
	30	0.570±0.107	1.028±0.485 (+30.35%)	1.381±0.088 (+142.28%)	1.677±0.146 (+194.21%)	2.019±0.191 (+253.86%)	2.256±0.205 (+295.79%)	Temperature = 0.007
	40[a]	0.600±0.106	1.052±0.205 (+75.33%)	1.387±0.208 (+131.17%)	1.727±0.192 (+187.83%)	2.037±0.192 (+239.50%)	2.300±0.196 (+283.33%)	Interaction = 0.017
	50[b]	0.580±0.080	1.041±0.11 (+79.48%)	1.416±0.195 (+144.14%)	1.755±0.103 (+202.59%)	2.053±0.194 (+253.97%)	2.285±0.208 (+293.97%)	
Potassium (mg L^{-1})	10	13.43±2.01	13.30±1.01 (−0.97%)	13.41±1.01 (−0.15%)	13.40±1.00 (−0.22%)	13.35±2.00 (−0.60%)	13.10±0.99 (−2.46%)	
	20	13.40±1.00	13.28±1.99 (−0.90%)	13.35±1.00 (−0.37%)	13.21±0.99 (−1.42%)	13.32±2.11 (−0.60%)	13.04±1.02 (−2.69%)	Treatment = NS
	30	13.36±1.00	13.24±2.0 (−0.90%)	13.32±1.01 (−0.30%)	13.16±1.00 (−1.50%)	13.33±0.99 (−0.22%)	13.05±2.53 (−2.32%)	Temperature = NS
	40[a]	13.42±0.99	13.32±1.01 (−0.75%)	13.42±2.00 (+0.00%)	13.31±2.01 (−0.82%)	13.29±1.99 (−0.97%)	13.09±0.99 (−2.38%)	Interaction = NS
	50[b]	13.43±1.01	13.31±2.01 (−0.89%)	13.42±2.00 (−0.07%)	13.31±1.99 (−0.89%)	13.34±1.0 (−0.67%)	13.12±2.01 (−2.31%)	

Mean ± SD, with in parenthesis percent variation over the control
[a] studied in samples collected at 9th day after the death of plants
[b] studied in samples collected at 5th day after the death of plants

Table 12.17 Growth response of *Lemna minor* treated in small plastic pots with varying concentrations of Surf Excel at varying pH levels

Parameters	pH	Concentration (ppm)						LSD at 5 %
		0	10	20	30	40	50	
Dry weight (mg/g)	8.0	117.6 ± 2.7	120.3 ± 2.2 (+2.30 %)	121.9 ± 3.6 (+3.66 %)	129.3 ± 2.8 (+9.94 %)	132.0 ± 1.8 (+12.24 %)	129.9 ± 3.92 (+10.46 %)	
	7.5	116.2 ± 2.6	121.4 ± 1.6 (+4.48 %)	123.5 ± 2.6 (+6.28 %)	127.9 ± 4.0 (+10.07 %)	130.5±4.1 (+12.31 %)	131.2 ± 5.6 (+12.91 %)	Treatment = 9.18
	7.0	119.8 ± 4.2	122.3 ± 2.2 (+2.09 %)	127.3 ± 2.3 (+6.26 %)	134.8 ± 1.8 (+12.52 %)	128.7 ± 1.8 (+7.43 %)	132.8 ± 3.0 (+10.85 %)	pH = NS
	6.5	118.7 ± 2.7	125.4 ± 1.5 (+5.64 %)	129.3 ± 1.3 (+8.93 %)	132.9 ± 5.3 (+11.96 %)	136.7 ± 2.0 (+15.16 %)	137.5 ± 2.8 (+15.84 %)	Interaction = NS
	6.0	119.8 ± 4.1	123.6 ± 2.9 (+3.60 %)	125.3 ± 2.5 (+5.03 %)	131.1 ± 3.2 (+9.89 %)	134.7 ± 4.1 (+12.91 %)	131.5 ± 2.7 (+10.23 %)	
Chlorophyll-a (mg/g)	8.0	0.564 ± 0.070	0.618 ± 0.073 (+9.57 %)	0.641 ± 0.078 (+13.65 %)	0.725 ± 0.045 (+28.65 %)	0.726 ± 0.099 (+28.72 %)	0.707 ± 0.077 (+25.35 %)	
	7.5	0.589 ± 0.018	0.603 ± 0.088 (+2.38 %)	0.652 ± 0.154 (+10.70 %)	0.738 ± 0.030 (+25.30 %)	0.743 ± 0.063 (+26.15 %)	0.710 ± 0.086 (+20.54 %)	Treatment = 0.060
	7.0	0.577 ± 0.054	0.618 ± 0.082 (7.11 %)	0.666 ± 0.070 (+15.42 %)	0.762 ± 0.081 (+32.06 %)	0.730 ± 0.050 (+26.52 %)	0.770 ± 0.053 (+33.45 %)	pH = NS
	6.5	0.629 ± 0.053	0.692 ± 0.080 (10.02 %)	0.683 ± 0.082 (+8.59 %)	0.754 ± 0.109 (+19.89 %)	0.764 ± 0.076 (+21.46 %)	0.788 ± 0.074 (+23.69 %)	Interaction = NS
	6.0	0.594 ± 0.095	0.607 ± 0.106 (+2.19 %)	0.671 ± 0.083 (+12.96 %)	0.772 ± 0.068 (+29.97 %)	0.700 ± 0.051 (+17.85 %)	0.753 ± 0.084 (+26.77 %)	
Chlorophyll-b (mg/g)	8.0	0.260 ± 0.028	0.301 ± 0.015 (+15.77 %)	0.291 ± 0.032 (+11.92 %)	0.346 ± 0.048 (+33.08 %)	0.352 ± 0.038 (+35.38 %)	0.360 ± 0.045 (+38.46 %)	
	7.5	0.277 ± 0.016	0.311 ± 0.036 (+12.27 %)	0.301 ± 0.064 (+8.66 %)	0.365 ± 0.053 (+31.77 %)	0.325 ± 0.047 (+17.33 %)	0.384 ± 0.033 (+38.63 %)	Treatment = 0.031
	7.0	0.317 ± 0.024	0.364 ± 0.017 (+14.83 %)	0.344 ± 0.077 (+8.52 %)	0.399 ± 0.052 (+25.87 %)	0.360 ± 0.049 (+13.56 %)	0.373 ± 0.038 (+17.67 %)	pH = NS
	6.5	0.330 ± 0.029	0.376 ± 0.023 (13.94 %)	0.344 ± 0.049 (+4.24 %)	0.381 ± 0.043 (+15.45 %)	0.452 ± 0.097 (+36.96 %)	0.404 ± 0.042 (+22.42 %)	Interaction = NS
	6.0	0.278 ± 0.023	0.316 ± 0.023 (+13.67 %)	0.325 ± 0.055 (+16.91 %)	0.368 ± 0.029 (+32.37 %)	0.392 ± 0.033 (+41.0 %)	0.386 ± 0.047 (+38.84)	
Total chlorophyll (mg/g)	8.0	0.874 ± 0.123	0.915 ± 0.055 (+4.69 %)	1.002 ± 0.143 (+14.65 %)	1.195 ± 0.224 (+36.73 %)	1.148 ± 0.138 (+31.35 %)	1.182 ± 0.115 (+35.24 %)	
	7.5	0.887 ± 0.093	0.940 ± 0.102 (+4.69 %)	1.048 ± 0.093 (+18.15 %)	1.168 ± 0.222 (+31.68 %)	1.192 ± 0.176 (+34.39 %)	1.209 ± 0.136 (+36.30 %)	Treatment = 0.105
	7.0	0.897 ± 0.097	0.962 ± 0.152 (+7.25 %)	1.021 ± 0.116 (+13.82 %)	1.204 ± 0.178 (+34.23 %)	1.157 ± 0.176 (+28.99 %)	1.193 ± 0.134 (+33.00 %)	pH = NS
	6.5	0.978 ± 0.059	1.057 ± 0.163 (+8.08 %)	1.012 ± 0.049 (+3.48 %)	1.205 ± 0.130 (+23.11 %)	1.204 ± 0.11 (+23.11 %)	1.233 ± 0.154 (+26.07 %)	Interaction = NS
	6.0	0.965 ± 0.087	0.910 ± 0.081 (+5.70 %)	1.026 ± 0.081 (+6.32 %)	1.173 ± 0.164 (+21.55 %)	1.213 ± 0.205 (+25.70 %)	1.239 ± 0.159 (+28.39 %)	
Nitrogen (mg/100mg)	8.0	2.87 ± 0.09	3.08 ± 0.52 (+7.46 %)	3.71 ± 0.25 (+29.49 %)	3.53 ± 0.32 (+23.08 %)	3.18 ± 0.36 (+10.74 %)	3.73 ± 0.18 (+29.99 %)	
	7.5	2.88 ± 0.43	3.13 ± 0.24 (+8.68 %)	3.70 ± 0.37 (+28.52 %)	3.36 ± 0.35 (+16.57 %)	3.62 ± 0.48 (+25.88 %)	3.83 ± 0.19 (+32.96 %)	Treatment = 0.24
	7.0	2.99 ± 0.27	3.44 ± 0.24 (+14.99 %)	3.72 ± 0.25 (+24.50 %)	3.05 ± 0.32 (+2.14 %)	3.82 ± 0.23 (+27.98 %)	4.13 ± 0.28 (+38.15 %)	pH = 0.21
	6.5	3.10 ± 0.42	3.73 ± 0.24 (+20.27 %)	3.78 ± 0.52 (+22.01 %)	3.21 ± 0.47 (+3.68 %)	3.95 ± 0.34 (+27.43 %)	4.00 ± 0.16 (+29.24 %)	Interaction = 0.53
	6.0	3.04 ± 0.20	3.30 ± 0.10 (+8.72 %)	3.90 ± 0.21 (+28.37 %)	3.42 ± 0.24 (+12.44 %)	4.01 ± 0.13 (+31.93 %)	3.95 ± 0.31 (+29.95 %)	
Phosphorus (mg/100mg)	8.0	0.241 ± 0.034	0.259 ± 0.026 (+7.47 %)	0.264 ± 0.083 (+9.96 %)	0.336 ± 0.071 (+39.41 %)	0.336 ± 0.066 (+39.41 %)	0.330 ± 0.058 (+39.93 %)	
	7.5	0.269 ± 0.061	0.299 ± 0.054 (+11.15 %)	0.272 ± 0.054 (+1.12 %)	0.346 ± 0.051 (+28.62 %)	0.351 ± 0.065 (+30.48 %)	0.371 ± 0.056 (+37.92 %)	Treatment = 0.042
	7.0	0.253 ± 0.048	0.273 ± 0.054 (+11.15 %)	0.355 ± 0.099 (+40.32 %)	0.298 ± 0.074 (+17.79 %)	0.338 ± 0.077 (+33.60 %)	0.321 ± 0.043 (+26.88 %)	pH = 0.038
	6.5	0.299 ± 0.074	0.333 ± 0.077 (+11.37 %)	0307 ± 0.054 (+26.76 %)	0.382 ± 0.026 (+27.59 %)	0.422 ± 0.021 (+41.14 %)	0.416 ± 0.035 (+39.13 %)	Interaction = NS
	6.0	0.283 ± 0.048	0.360 ± 0.44 (+27.20 %)	0.288 ± 0.041 (+1.77 %)	0.365 ± 0.053 (+28.98 %)	0.369 ± 0.053 (+30.39 %)	0.388 ± 0.032 (+37.10 %)	
Potassium (mg/100mg)	8.0	1.71 ± 0.34	1.77 ± 0.43 (+3.21 %)	2.11 ± 0.31 (+23.42 %)	1.82 ± 0.30 (+8.12 %)	2.14 ± 0.29 (+24.7 %)	2.12 ± 0.45 (+24.01 %)	
	7.5	1.71 ± 0.52	1.73 ± 0.36 (+1.41 %)	1.99 ± 0.32 (+16.33 %)	2.30 ± 0.37 (+34.36 %)	2.25 ± 0.29 (+31.79 %)	2.24 ± 0.24 (+31.15 %)	Treatment = 0.33
	7.0	1.72 ± 0.37	1.73 ± 0.42 (+0.02 %)	1.97 ± 0.46 (+14.04 %)	2.23 ± 0.29 (+29.29 %)	2.28 ± 0.54 (+31.96 %)	2.82 ± 0.49 (+32.37 %)	pH = NS
	6.5	1.80 ± 0.30	1.87 ± 0.55 (+3.55 %)	2.00 ± 0.11 (+11.15 %)	2.32 ± 0.19 (+28.58 %)	2.30 ± 0.27 (+27.80 %)	2.29 ± 0.29 (+27.08 %)	Interaction = NS
	6.0	1.78 ± 0.56	1.81 ± 0.43 (+1.35 %)	2.02 ± 0.18 (+13.58 %)	2.27 ± 0.260 (+27.27 %)	2.26 ± 0.37 (+26.99 %)	2.25 ± 0.37 (+26.43 %)	

Mean ± SD, with in parenthesis percent variation over the control

Table 12.18 Physico–chemical characteristics of water containing varying concentrations of Surf Excel detergent maintained at varying pH levels studied after 11th day of growth of *Lemna minor*

Parameters	pH	Concentration (ppm)						LSD at 5%
		0	10	20	30	40	50	
Turbidity (NTU)	8.0	10±1.0	11±0.0 (+11%)	13±2.0 (+30%)	15±1.0 (+50%)	15±2.0 (+50%)	16±3.0 (+60 %)	
	7.5	11±2.0	12±2.0 (+9.09%)	14±3.0 (+27.27%)	15±2.s0 (+36.36%)	16±4.0 (+45.45%)	18±5.0 (+63.63%)	Treatment = NS
	7.0	10±2.0	13±1.0 (+30%)	15±2.0 (+50%)	16±4.0 (+60%)	18±2.0 (+80%)	18±3.0 (+80%)	pH = NS
	6.5	11±3.0	12±2.0 (+9.09%)	13±3.0 (+18.18%)	15±1.0 (+36.36%)	17±1.0 (+54.55%)	18±2.0 (+63.64%)	Interaction = NS
	6.0	11±1.0	12±2.0 (+9.09%)	12±3.0 (+9.09%)	14±4.0 (+27.27%)	15±2.0 (+36.36%)	17±1.0 (+54.55%)	
Dissolved oxygen (mg L^{-1})	8.0	6.9±0.2	6.7±0.2 (−2.90%)	6.3±0.1 (−8.70%)	5.5±0.0 (−20.29%)	5.6±0.4 (−18.84%)	5.4±0.3 (−21.74%)	
	7.5	6.6±0.3	6.2±0.2 (−6.06%)	6.2±0.4 (−6.06%)	5.2±0.4 (−21.21%)	5.3±0.4 (−19.70%)	5.8±0.5 (−12.12%)	Treatment = 0.27
	7.0	6.8±0.5	6.5±0.3 (−4.41%)	6.1±0.6 (−10.29%)	5.7±0.1 (−16.18%)	5.4±0.3 (−20.59%)	5.0±0.4 (−26.47%)	pH = NS
	6.5	6.8±0.2	6.6±0.5 (−2.94%)	6.1±0.6 (−10.29%)	5.5±0.1 (−19.12%)	5.9±0.3 (−13.24%)	5.0±0.3 (−26.47%)	Interaction = NS
	6.0	6.9±0.3	6.9±0.4 (−0.00%)	6.1±0.5 (−11.59%)	5.7±0.4 (−17.39%)	5.6±0.4 (−18.84%)	5.1±0.2 (−26.09%)	
Nitrates (mg L^{-1})	8.0	0.681±0.193	0.610±0.111 (−10.43%)	0.631±0.163 (−7.34%)	0.637±0.056 (−6.46%)	0.535±0.056 (−21.44%)	0.607±0.084 (−10.87%)	
	7.5	0.687±0.191	0.666±0.132 (−3.06%)	0.683±0.174 (−0.58%)	0.599±0.134 (−12.81%)	0.573±0.093 (−16.59%)	0.623±0.078 (−9.32%)	Treatment = 0.202
	7.0	0.643±0.123	0.713±0.145 (−10.89%)	0.572±0.064 (−11.04%)	0.551±0.098 (−14.31%)	0.623±0.050 (−3.11%)	0.570±0.134 (−11.35%)	pH = NS
	6.5	0.603±0.118	0.550±0.116 (−8.79%)	0.529±0.132 (+12.27%)	0.558±0.083 (−7.46%)	0.513±0.038 (−14.93%)	0.541±0.161 (−10.28%)	Interaction = NS
	6.0	0.735±0.160	0.626±0.153 (−14.83%)	0.678±0.145 (−7.76%)	0.586±0.134 (−20.27%)	0.587±0.092 (−20.14%)	0.584±0.147 (−20.34%)	
Phosphates (mg L^{-1})	8.0	0.600±0.111	1.074±0.089 (+79.00%)	1.398±0.233 (+133.00%)	1.717±0.332 (+186.17%)	2.028±0.280 (+238.00%)	2.294±0.319 (+282.33%)	
	7.5	0.620±0.163	1.056±0.161 (+70.32%)	1.354±0.266 (+118.39%)	1.698±0.449 (+173.87%)	2.008±0.140 (+223.87%)	2.275±0.275 (+266.94%)	Treatment = 0.095
	7.0	0.670±0.109	1.029±0.053 (+53.58%)	1.378±0.178 (+105.67%)	1.668±0.280 (+148.96%)	2.065±0.387 (+208.21%)	2.230±0.239 (+232.84%)	pH=NS
	6.5	0.650±0.124	1.011±0.137 (+55.54%)	1.311±0.340 (+115.65%)	1.622±0.317 (+149.54%)	1.957±0.456 (+201.68%)	2.203±0.103 (+238.92%)	Interaction = NS
	6.0	0.620±0.105	0.983±0.251 (+58.55%)	1.337±0.340 (+115.65%)	1.651±0.364 (+166.29%)	1.928±0.369 (+210.97%)	2.246±0.351 (+262.26%)	
Potassium (mg L^{-1})	8.0	13.49±1.51	13.48±1.40 (−0.07%)	13.14±1.25 (−2.59%)	13.37±1.27 (−0.89%)	13.32±1.28 (−1.26%)	13.35±1.39 (−0.96%)	
	7.5	13.46±0.95	13.40±1.54 (−0.45%)	13.34±1.80 (−0.89%)	13.79±1.57 (−2.45%)	13.34±1.38 (−0.66%)	13.29±1.60 (−1.26%)	Treatment = NS
	7.0	13.47±1.42	13.40±1.68 (−0.52%)	13.12±1.00 (−2.60%)	13.25±1.21 (−1.63%)	13.24±1.14 (−1.71%)	13.22±1.11 (−1.86%)	pH = NS
	6.5	13.43±1.23	13.41±0.41 (−0.15%)	13.13±1.23 (−2.23%)	13.31±1.43 (−0.89%)	13.33±1.45 (−0.74%)	13.26±0.76 (−1.27%)	Interaction = NS
	6.0	13.40±1.50	13.36±1.34 (−0.30%)	13.29±1.60 (−0.82%)	13.76±1.28 (−2.69%)	13.24±0.84 (−1.19%)	13.27±1.25 (−0.97%)	

Mean ± SD, within parenthesis percent variation over the control

Table 12.19 Growth response of *Spirodela polyrrhiza* treated in small plastic pots with varying concentrations of Surf Excel at varying pH levels

Parameters	pH	Concentration (ppm)						LSD at 5%
		0	10	20	30	40	50	
Dry weight (mg/g)	8.0	122.73±2.17	127.53±2.9 (+3.91%)	132.83±2.16 (+8.23%)	133.53±3.7 (+8.82%)	134.63±2.15 (+9.70%)	125.53±4.08 (+2.12%)	
	7.5	123.93±3.19	126.93±4.2 (+2.42%)	133.23±3.17 (+7.50%)	134.83±2.17 (+8.80%)	135.20±2.91 (+9.44%)	127.42±4.07 (+2.82%)	Treatment = 0.12
	7.0	124.53±4.16	129.83±3.13 (+4.26%)	136.73±0.85 (+9.80%)	134.33±1.86 (+7.87%)	138.13±4.84 (+10.92%)	125.03±1.16 (+0.40%)	pH = 0.11
	6.5	127.53±0.96	128.33±1.84 (+0.63%)	135.33±1.15 (+6.12%)	137.03±7.35 (+7.45%)	135.53±3.17 (+6.27%)	128.23±3.07 (+0.55%)	Interaction = 0.27
	6.0	126.40±1.19	131.53±1.12 (+4.06%)	134.03±3.86 (+6.04%)	138.53±0.84 (+9.60%)	139.42±1.4 (+10.30%)	128.53±1.14 (+1.69%)	
Chlorophyll-a (mg/g)	8.0	0.639±0.057	0.643±0.044 (+0.63%)	0.670±0.071 (+4.85%)	0.743±0.044 (+16.28%)	0.759±0.059 (+18.78%)	0.789±0.059 (+23.47%)	
	7.5	0.658±0.025	0.687±0.069 (+4.41%)	0.693±0.074 (+5.32%)	0.733±0.034 (+11.40%)	0.788±0.049 (+18.23%)	0.770±0.054 (+17.02%)	Treatment = 0.026
	7.0	0.677±0.048	0.738±0.038 (+9.01%)	0.688±0.058 (+1.62%)	0.770±0.042 (+13.73%)	0.809±0.039 (+19.50%)	0.795±0.069 (+17.43%)	pH = 0.026
	6.5	0.626±0.033	0.643±0.021 (+2.72%)	0.677±0.048 (+8.15%)	0.817±0.039 (+30.51%)	0.776±0.049 (+23.96%)	0.816±0.059 (+30.35%)	Interaction = 0.054
	6.0	0.603±0.047	0.647±0.048 (+7.30%)	0.703±0.027 (+16.58%)	0.789±0.021 (+30.84%)	0.803±0.039 (+33.17%)	0.826±0.044 (+36.98%)	
Chlorophyll-b (mg/g)	8.0	0.325±0.039	0.337±0.032 (+3.69%)	0.380±0.059 (+16.92%)	0.421±0.042 (+29.54%)	0.441±0.036 (+35.69%)	0.452±0.035 (+39.08%)	
	7.5	0.327±0.039	0.333±0.021 (+1.83%)	0.386±0.038 (+18.04%)	0.429±0.37 (+31.19%)	0.459±0.038 (+40.37%)	0.450±0.037 (+37.61%)	Treatment = 0.026
	7.0	0.336±0.040	0.348±0.041 (+3.57%)	0.402±0.039 (+19.64%)	0.446±0.045 (+32.74%)	0.462±0.042 (+37.50%)	0.476±0.039 (+41.67%)	pH = 0.026
	6.5	0.333±0.036	0.363±0.039 (+9.0%)	0.397±0.029 (+19.22%)	0.441±0.029 (+32.43%)	0.470±0.059 (+41.14%)	0.467±0.033 (+38.80%)	Interaction = 0.054
	6.0	0.341±0.038	0.352±0.023 (+3.22%)	0.413±0.043 (+21.11%)	0.457±0.028 (+34.02%)	0.478±0.028 (+40.18%)	0.487±0.032 (+42.80%)	
Total chlorophyll (mg/g)	8.0	0.959±0.065	0.993±0.061 (+3.55%)	1.087±0.024 (+13.35%)	1.224±0.067 (+27.63%)	1.261±0.103 (+31.49%)	1.279±0.103 (+33.37%)	
	7.5	0.964±0.120	0.997±0.089 (+3.42%)	1.081±0.053 (+12.14%)	1.230±0.101 (+27.59%)	1.285±0.056 (+33.30%)	1.267±0.074 (+31.43%)	Treatment = 0.075
	7.0	0.977±0.098	1.020±0.092 (+4.40%)	1.092±0.075 (+11.77%)	1.239±0.126 (+26.82%)	1.276±0.038 (+30.60%)	1.298±0.101 (+32.85%)	pH = NS
	6.5	0.973±0.129	1.036±0.099 (+6.47%)	1.098±0.064 (+12.85%)	1.252±0.109 (+28.67%)	1.272±0.019 (+30.73%)	1.302±0.052 (+33.81%)	Interaction = NS
	6.0	0.987±0.084	1.021±0.074 (+3.44%)	1.109±0.024 (+12.36%)	1.242±0.085 (+25.84%)	1.297±0.051 (+31.41%)	1.282±0.049 (+29.89%)	
Nitrogen (mg/100 mg)	8.0	2.96±0.08	3.22±0.09 (+8.78%)	3.82±0.081 (+29.05%)	3.47±0.095 (+17.23%)	3.99±0.070 (+34.79%)	4.01±0.046 (+35.47%)	
	7.5	2.93±0.06	3.18±0.04 (+8.64%)	3.88±0.094 (+32.56%)	3.52±0.085 (+20.26%)	3.91±0.090 (+33.58%)	4.21±0.051 (+43.83%)	Treatment = 0.065
	7.0	3.07±0.19	3.33±0.10 (+8.47%)	3.98±0.081 (+29.64%)	4.04±0.081 (+31.59%)	4.14±0.081 (+34.85%)	4.10±0.064 (+33.55%)	pH = 0.059
	6.5	3.16±0.09	3.47±0.042 (+9.81%)	3.99±0.081 (+26.27%)	3.68±0.070 (+16.45%)	4.26±0.061 (+34.81%)	4.10±0.063 (+29.75%)	Interaction = NS
	6.0	3.13±0.14	3.37±0.09 (+7.77%)	4.15±0.085 (+32.72%)	3.63±0.88 (+16.09%)	4.25±0.056 (+35.91%)	4.37±0.051 (+39.75%)	
Phosphorus (mg/100 mg)	8.0	0.298±0.049	0.333±0.028 (+11.74%)	0.312±0.019 (+4.70%)	0.386±0.015 (+29.53%)	0.363±0.033 (+21.81%)	0.372±0.025 (+24.83%)	
	7.5	0.300±0.058	0.363±0.033 (+21.00%)	0.333±0.029 (+11.67%)	0.406±0.018 (+35.33%)	0.378±0.0150 (+26.0%)	0.377±0.021 (+25.67%)	Treatment = 0.017
	7.0	0.316±0.039	0.347±0.028 (+9.81%)	0.325±0.028 (+2.85%)	0.396±0.012 (+19.62%)	0.417±0.027 (+31.96%)	0.386±0.022 (+25.32%)	pH = 0.016
	6.5	0.310±0.068	0.338±0.063 (+9.03%)	0.316±0.029 (+1.94%)	0.391±0.025 (+25.81%)	0.384±0.016 (+23.87%)	0.393±0.018 (+26.77%)	Interaction = 0.035
	6.0	0.306±0.038	0.352±0.011 (+15.03%)	0.338±0.013 (+10.46%)	0.405±0.014 (+32.35%)	0.368±0.024 (+20.26%)	0.400±0.020 (+30.72%)	
Potassium (mg/100 mg)	8.0	1.87±0.04	2.04±0.10 (+4.32%)	1.95±0.21 (+3.74%)	2.28±0.31 (+21.61%)	2.03±0.21 (+8.27%)	2.05±0.31 (+9.61%)	
	7.5	1.87±0.11	2.04±0.33 (+8.80%)	1.94±0.42 (+3.58%)	2.76±0.31 (+21.45%)	2.02±0.34 (+8.00%)	1.94±0.32 (+3.89%)	Treatment = 0.29
	7.0	1.88±0.20	1.89±0.20 (+0.59%)	1.93±0.21 (+2.88%)	2.28±0.33 (+21.26%)	2.05±0.25 (+9.75%)	1.90±0.39 (+1.17%)	pH = NS
	6.5	1.87±0.21	1.88±0.30 (+0.96%)	2.03±0.31 (+8.94%)	2.04±0.31 (+8.90%)	2.05±0.32 (+9.70%)	2.02±0.21 (+8.03%)	Interaction = NS
	6.0	1.89±0.32	2.09±0.14 (+10.83%)	2.02±0.21 (+6.81%)	2.31±0.38 (+22.13%)	2.06±0.31 (+8.98%)	2.10±0.26 (+10.78%)	

Mean ± SD, within parenthesis percent variation over the control

specifically with the detergent concentration rather than pH. The significant uptake of phosphorus in *Spirodela polyrrhiza* was recorded in 30, 40, and 50 ppm detergent solution at almost all pH levels ranging from 6.0 to 8.0 (Table 12.19).

12.3.6.4 Water Quality

Table 12.20 comprises the data on the physico–chemical characteristics of water with varying concentrations of Surf Excel analyzed after the growth of *Spirodela polyrrhiza*. A glance on the data shows that the turbidity was higher in the solutions of acidic pH 6.0 than in the solution of alkaline pH 8.0. The turbidity was also found to be higher in the detergent solution of 40 and 50 ppm concentration. The turbidity of the detergent solutions at all pH levels was higher. The dissolved oxygen consistently decreased with the increase in the concentration of Surf Excel at all pH levels. The dissolved oxygen at lower pH showed a significant reduction even at lower concentration of the detergent. The nitrate content was highest in control at neutral pH. The nitrates at pH 8.0 did not show much variation at 10 ppm concentration. But at higher concentration (50 ppm), the nitrate contents were lower at pH 6.5–7.5 than in control (probably owing to greater uptake). The phosphates were more significantly related with the concentration of Surf Excel and not with the pH. The potassium contents were slightly lower in Surf Excel solutions as compared to control probably owing to higher uptake of potassium (Table 12.20).

12.4 Discussion

In the screening experiments with 36 selected detergents it was recorded that the dry weight of both the selected duckweeds increased in response to varying detergent concentrations. The growth, (in the form of dry weight) varied with the detergent types and its concentrations. There were three general types of growth pattern. The variation in the type of growth response may be owing to the variations in the relative proportion of constituents of the detergents. There might have been some variation in the relative proportion of the phosphorus content as well. It is evident from the experiments with varying concentrations of Surf Excel (conducted in the polyvinyl and earthen pots) that enough phosphorus was available in the water even after the adequate uptake. Thus, the variation in phosphorus content alone may have not caused variation in responses of the duckweeds to the selected detergents. The detergents used in the present study might have caused varying degree of changes in the water quality parameters.

Some of the factors which affects the growth and development of the aquatic plants include turbidity, temperature, nutrients, dissolved oxygen, CO_2, light, and pH. Shen Dong Sheng and Shen (2002) noted that light intensity, temperature, and nutrients (mainly phosphorus and nitrogen) influenced the algal population in the river network of Zhejiang, China. The phosphorus was considered to be the major determinant in regulating the algal biomass (Shen Dong Sheng and Shen 2002, Kwang-Guk et al. 2003). All the 36 detergents studied might have resulted into the three major sets of aquatic environments with their specific growth responses (Tables 12.5, 12.6, 12.7 and 12.8).

The Surf Excel (a commonly used detergent in India) was selected for the detailed studies on the responses of two selected weeds. Both the duckweeds (in screening experiment) showed type-B growth pattern in response to Surf Excel. The optimum growth of both the duckweeds was observed at 30 ppm of Surf Excel. The duckweeds were studied for their growth responses in large 15 L earthen pots and 150 mL polyvinyl pots to work out the impact of space and volume of the medium. The aquatic microcosm systems have been evaluated as a tool for the quantitative description of phytoplankton, bacteria their nutrient relationship and nutrient cycling in the eutrophication studies (Tsirtsis and Karydis 1997).

In the screening experiments with 36 detergents, three concentrations of the selected detergents (viz., 10, 30, and 50 ppm) were used to study the growth responses of the selected duckweeds. However, in the earthen pot experiment, five concentration levels (10, 20, 30, 40, and 50 ppm) of Surf Excel were used. In the later experiment, the peak of growth of *Lemna minor* was observed at 40 ppm level of Surf Excel. The Surf Excel concentration level up to 50 ppm increased the dry weight accumulation and uptake of phosphorus and nitrogen in *Lemna minor*. The chlorophyll content in *Lemna minor* increased only at lower concentrations (Table 12.9).

The varying concentration of Surf Excel changed the water quality in proportion to their concentration as evident from the data summarized in Table 12.10. The pH, turbidity, and dissolved oxygen varied noticeably with the detergent concentration. The higher pH in the present study retarded the growth of *Lemna minor* and *Spirodela polyrrhiza* (Tables 12.10 and 12.12). It is evident that in addition to phosphate availability, the water quality played more effective role in enhancing the growth of the plants. As evident from the data (Table 12.10), 50 ppm of Surf Excel detergent at lower pH were significantly more effective in promoting the growth of *Lemna minor* as compared to higher pH. The water quality analysis of earthen pots showed 8.8 ± 0.2 pH at 50 ppm of Surf Excel (Table 12.10).

The availability of ions to plant roots has been found to be profoundly affected by hydrogen ion concentration. The monovalent phosphate ion ($H_2PO_4^-$) formed at acidic pH becomes more readily available to the plants. When the medium approaches towards a more alkaline environment, first the production of bivalent phosphate (HPO_4^{2-}) and thereafter the trivalent phosphate (PO_4^{3-}) ions is favored. The biva-

Table 12.20 Physico–chemical characteristics of water containing varying concentrations of Surf Excel detergent maintained at varying pH levels studied after 11th day of growth of *Spirodela polyrrhiza*

Parameters	pH	Concentration (ppm)						LSD at 5 %
		0	10	20	30	40	50	
Turbidity (NTU)	8.0	11 ± 1	12 ± 2 (+9.09 %)	13 ± 1 (+18.18 %)	15 ± 3 (+36.36 %)	15 ± 2 (+36.36 %)	16 ± 3 (+45.45 %)	
	7.5	12 ± 1	13 ± 1 (+8.33 %)	14 ± 2 (+16.67 %)	16 ± 2 (+33.33 %)	17 ± 2 (+41.67 %)	18 ± 3 (+50 %)	Treatment = 1.13
	7.0	12 ± 1	14 ± 2 (+16.67 %)	14 ± 3 (+16.67 %)	15 ± 1 (+25 %)	16 ± 2 (+33.33 %)	17 ± 2 (+41.67 %)	pH = 1.03
	6.5	12 ± 1	13 ± 1 (+8.33 %)	15 ± 1 (+25 %)	16 ± 2 (+33.33 %)	18 ± 1 (+50 %)	18 ± 1 (+50 %)	Interaction = NS
	6.0	12 ± 2	14 ± 1 (+16.67 %)	14 ± 2 (+16.67 %)	15 ± 3 (+25 %)	17 ± 2 (+41.67 %)	19 ± 3 (+58.33 %)	
Dissolved oxygen (mg L^{-1})	8.0	6.81 ± 0.65	6.66 ± 0.19 (−2.20 %)	6.15 ± 0.38 (−9.69 %)	5.16 ± 0.30 (−24.23 %)	5.44 ± 0.31 (−20.11 %)	4.93 ± 0.28 (−27.61 %)	
	7.5	6.76 ± 0.49	6.62 ± 0.27 (−2.07 %)	6.51 ± 0.52 (−3.70 %)	5.73 ± 0.30 (−15.24 %)	4.93 ± 0.44 (−27.07 %)	5.01 ± 0.17 (−25.89 %)	Treatment = 0.064
	7.0	6.62 ± 0.54	6.38 ± 0.20 (−3.63 %)	6.10 ± 0.50 (−7.85 %)	5.16 ± 0.65 (−22.05 %)	5.06 ± 0.42 (−23.56 %)	4.80±0.45 (−27.79 %)	pH = 0.059
	6.5	6.38 ± 0.53	6.03 ± 0.33 (−5.49 %)	5.97 ± 0.55 (−6.43 %)	5.20 ± 0.66 (−18.50 %)	5.22 ± 0.40 (−18.18 %)	4.61 ± 0.39 (−27.74 %)	Interaction = 0.144
	6.0	6.56 ± 0.52	6.08 ± 0.45 (−7.32 %)	6.31 ± 0.32 (−3.81 %)	4.79 ± 0.36 (−26.98 %)	5.31 ± 0.25 (−19.05 %)	4.66 ± 0.59 (−28.96 %)	
Nitrates (mg L^{-1})	8.0	0.632 ± 0.045	0.628 ± 0.048 (−0.63 %)	0.612 ± 0.080 (−3.13 %)	0.605 ± 0.063 (−4.23 %)	0.622 ± 0.044 (−1.58 %)	0.594 ± 0.048 (−6.01 %)	
	7.5	0.644 ± 0.029	0.582 ± 0.044 (−9.63 %)	0.639 ± 0.048 (−0.78 %)	0.618 ± 0.050 (−4.04 %)	0.601 ± 0.051 (−6.68 %)	0.555 ± 0.034 (−13.82 %)	Treatment = 0.016
	7.0	0.648 ± 0.037	0.631 ± 0.070 (−2.62 %)	0.611 ± 0.086 (−5.71 %)	0.632 ± 0.065 (−2.47 %)	0.605 ± 0.048 (−6.64 %)	0.590 ± 0.045 (−8.95 %)	pH = 0.015
	6.5	0.626 ± 0.052	0.584 ± 0.056 (−3.71 %)	0.581 ± 0.065 (−5.59 %)	0.618 ± 0.062 (−1.28 %)	0.616 ± 0.076 (−1.60 %)	0.571 ± 0.045 (−8.79 %)	Interaction = 0.034
	6.0	0.61 ± 0.077	0.598 ± 0.036 (−2.45 %)	0.546 ± 0.042 (−10.93 %)	0.550 ± 0.077 (−10.28 %)	0.590 ± 0.050 (−3.75 %)	0.576 ± 0.038 (−6.04 %)	
Phosphates (mg L^{-1})	8.0	0.654 ± 0.052	1.026 ± 0.109 (+56.88 %)	1.323 ± 0.110 (+102.29 %)	1.674 ± 0.201 (+155.96 %)	1.986 ± 0.250 (+203.67 %)	2.228 ± 0.406 (+240.67 %)	
	7.5	0.660 ± 0.061	0.997 ± 0.203 (+51.06 %)	1.357 ± 0.092 (+105.60 %)	1.646 ± 0.292 (+149.39 %)	1.947 ± 0.228 (+195.00 %)	2.247 ± 0.392 (+240.45 %)	Treatment = 0.095
	7.0	0.668 ± 0.067	1.004 ± 0.113 (+50.29 %)	1.326 ± 0.202 (+98.50 %)	1.665 ± 0.090 (+149.25 %)	1.956 ± 0.085 (+192.81 %)	2.254 ± 0.217 (+237.43 %)	pH = NS
	6.5	0.640 ± 0.048	10.17 ± 0.192 (+58.90 %)	1.309 ± 0.208 (+104.53 %)	1.639 ± 0.429 (+156.09 %)	1.978 ± 0.321 (+209.06 %)	2.204 ± 0.329 (+244.38 %)	
	6.0	0.643 ± 0.042	0.979 ± 0.115 (+52.26 %)	1.344 ± 0.102 (+109.02 %)	1.624 ± 0.332 (+152.27 %)	1.926 ± 0.260 (+199.33 %)	2.226 ± 0.195 (+246.19 %)	
Potassium (mg L^{-1})	8.0	13.24 ± 0.037	12.83 ± 0.052 (−3.09 %)	13.16 ± 0.048 (−0.60 %)	13.23 ± 0.032 (−0.08 %)	13.06 ± 0.029 (−1.36 %)	13.14 ± 0.040 (−0.76 %)	
	7.5	13.22 ± 0.074	12.81 ± 0.033 (−3.10 %)	13.17 ± 0.035 (−0.38 %)	13.17 ± 0.049 (−0.38 %)	13.00 ± 0.039 (−1.66 %)	13.15 ± 0.045 (−0.53 %)	Treatment = NS
	7.0	13.43 ± 0.055	13.35 ± 0.070 (−0.60 %)	13.11 ± 0.047 (−2.38 %)	13.21 ± 0.033 (−1.64 %)	13.25 ± 0.026 (−1.34 %)	13.31 ± 0.054 (−0.89 %)	pH = NS
	6.5	13.45 ± 0.082	13.30 ± 0.059 (−1.11 %)	13.20 ± 0.055 (−1.86 %)	13.19 ± 0.031 (−1.93 %)	13.28 ± 0.052 (−1.26 %)	13.33 ± 0.048 (−0.89 %)	Interaction = NS
	6.0	13.27 ± 0.038	12.85 ± 0.092 (−3.19 %)	13.24 ± 0.041 (−0.23 %)	13.16 ± 0.025 (−0.83 %)	13.14 ± 0.054 (−0.98 %)	13.21 ± 0.050 (−0.45 %)	

Mean ± SD, within parenthesis percent variation over the control

lent and trivalent forms of phosphate ions are not as readily available to the plants as monovalent phosphate ions (Devlin and Witham 1986). The data of Table 12.11 suggested that the 40 ppm of the Surf Excel increased the dry weight, chlorophyll content, and uptake of NPK in the *Spirodela polyrrhiza*.

It also emerged from the data that increasing concentration of Surf Excel resulted into a proportional increase in the pH of the water medium. Thus, despite increased availability of phosphate, probably its ionic forms consistently changed from monovalent to bivalent and trivalent ions which proportionally reduced the uptake of NPK in both the duckweeds at 50 ppm as compared to uptake at 40 ppm of Surf Excel (Tables 12.9 and 12.11). Moreover, the cells in the fronds of a *Lemna* species have proton extrusion pump at the plasmalemma which is responsible for the energy-dependent component of the membrane potential (Ansari and Khan 2006b; Novacky et al. 1978a, b; Löppert 1979; Jung and Lüttge 1980). This pump is responsible for the uptake of sugars, amino acids, phosphates, nitrates, and perhaps other inorganic ions by means of H^+-co transport mechanism (Ullrich-Eberius et al. 1978, 1981; Fischer and Lüttge 1980; Böcher et al. 1980; Lüttge et al. 1981).

The findings of the present work also established the ecological importance and sensitivity levels of the *Lemna minor*. Aziz and Mobina (1999) reported that pH 6.0 was most suitable for two species of *Spirodela polyrrhiza* and *Spirodelapunctata*. The *Spirodela polyrrhiza* died at pH 4.0. Both the species of *Spirodela* grew quite well up to pH 9. In both the species low pH affected the chlorophyll *b* formation (Aziz and Mobina 1999). Riis and Sand (1998) found a direct relationship between macrophyte distribution and pH, nutrient conditions, and transparency of Danish lakes.

The phosphorus is an important constituent of ATP, ADP, nucleic acids (DNA and RNA), phospholipids, and proteins. The meiotic cell division in sexual reproduction and mitotic cell division in vegetative propagation require greater supply of phosphorus for its binding into required nucleic acids, phospholipids, and protein. When grown singly, the phosphorus uptake in *Lemna minor* at 40 ppm of Surf Excel was almost 23 % higher than the control (Table 12.9). The phosphorus uptake in *Spirodela polyrrhiza* was 60 % higher (than the control) at 40 ppm of Surf Excel (Table 12.11).The plants have specific controls for the uptake of solutes, whether they have osmotic roles in the cells or the solutes are used as nutrients. The uptake of phosphate depends upon the phosphate status of the plants (Ullrich-Eberius et al. 1981).

A direct relationship between phytoplankton minima and maxima was found related with the DO content by a number of workers (Lande 1973; Misra et al. 1975; Saad 1973; Schindler 1971). As evident from the data of the water quality (Tables 12.10, 12.12) the dissolved oxygen and turbidity of water was impaired to a relatively greater extent by *Spirodela* sp. as compared to *Lemna* sp. Thus, the *Spirodela polyrrhiza* modifies the aquatic environment more actively than the *Lemna minor*. Such modifications in the environment by component species themselves, results into the succession of community to a higher seralstage. Any change in the natural quality of water is best reflected in the change in natural flora and fauna of the aquatic ecosystem (Kulshrestha et al. 1989). The eutrophication reduced the number of rare species and increased the abundance of meso- to hypereutrophic species specifically *Fragilariaberolinensis* in the eutrophic broad area of De NieuwkoopsePlassen in the Netherlands (Van Dam and Mertens 1993).

In the present work, temperature played important role in the growth of both the selected duckweed species. The optimum growth increase was noted at 30 °C temperature. The temperature of 20 and 30 °C increased the uptake of NPK specifically of phosphorus. The higher temperatures adversely affected the chlorophyll content in both the species eventually the excessive chlorosis and necrosis lead to faster duckweed mortality. The nitrogen uptake was optimum in both the species at 30 °C of temperature (Tables 12.15 and 12.17).The chlorophyll concentration was found strongly linked to the total nitrogen concentration. During summer, nitrogen concentrations accounted for about 60 % of the variability in chlorophyll concentration among different coastal systems (Neilson et al. 2002). It appears that higher temperature of 40 and 50 °C impaired the nitrogen availability and thereby reduced the chlorophyll content and thus, caused early disappearance of both the duckweeds by 5th to 9th day from the treatment. The temperature deviations are believed to impose stresses on plants leading to abnormalities resulting into reduced chances of survival (Ansari and Khan 2006b; Treshow 1970).

The temperature regulates cell division rate, enzyme activity (Giese 1979), translocation, and synthesis of food material (Devlin and Witham 1986). The development of plant, metabolic activities, mineral absorption, and water uptake are strongly temperature dependent (Treshow 1970; Devlin and Witham 1986). The lower temperatures below 10 °C (Ghosh et al. 1995) have been reported to retard the growth and productivity of duckweed. The temperature between 20 and 30 °C was found optimum by Hillman (1961). Aziz and Mobina (1999) found 25–33 °C temperature were optimum for the growth of two species of *Spirodela*. The photosynthesis is also dependent upon the enzyme activity which is reported to be negligible below 10 °C and to be optimum at 30 °C in most of the plant species (Treshow 1970). The role of several other parameters (viz. direct impact of detergents on the cell membranes, injuries and leakage of ions out of the fronds cells) in modifying the responses of both duckweeds cannot be ruled out. It is suggested that more detailed studies are needed to have a deeper insight on the physio–morphological responses of the duckweeds.

References

Ansari AA, Khan FA (2002) Nutritional status and quality of water of a waste water pond in Aligarh showing blooms of Spirodelapolyrrhiza (L.) Shleid. J Ecophysiol Occup Health 2:185–189

Ansari AA (2005) Studies on the role of selected household detergents in the eutrophication of freshwater ecosystem. PhD thesis, Aligarh Muslim University, Aligarh

Ansari AA, Khan FA (2006a) Studies on the role of some selected nutrient sources in the eutrophication of freshwater ecosystem. Natu Env Poll Technol 5:47–52

Ansari AA, Khan FA (2006b) Growth responses of Spirodelapolyrrhiza treated with a common detergent at varying temperature and pH conditions. Natu Env Poll Technol 5:399–404

Ansari AA, Khan FA (2007) Eutrophication studies on some freshwater ponds of Aligarh. Ind J Appl Pure Biol 22:21–26

Ansari AA, Khan FA (2008) Remediation of eutrophied water using Lemna minor in controlled Environment. Afric Jour Aqua Sci 33:275–278

Ansari AA, Khan FA (2009a) Eutrophication studies on Jeffery canal of Aligarh International Conference on Emerging Technologies in Environmental Science and Engineering. International Conference, Aligarh Muslim University, Aligarh, India, pp 845–849

Ansari AA, Khan FA (2009b) Remediation of eutrophied water using Spirodelapolyrrhiza (L.) Shleid in controlled environment. Pan-Americ J Aqua Sci 4:52–54

Ansari AA, Gill SS, Lanza GR, Rast W et al (2011a) Eutrophication: causes, consequences and control. Springer, The Netherlands p 394

Ansari AA, Gill SS, Khan FA et al (2011b) Eutrophication: threat to aquatic ecosystems. In: Ansari AA, Gill SS, Lanza GR, Rast W (eds) Eutrophication: causes, consequences and control. Springer, The Netherlands, pp 143–170

Ansari AA, Khan FA, Gill SS, Varshney J et al (2011c) Aquatic plant diversity in eutrophic ecosystems. In: Ansari AA, Gill SS, Lanza GR, Rast W (eds) Eutrophication: causes, consequences and control. Springer, The Netherlands, pp 247–263

Ansari AA, Khan FA (2011d) Nutrients phytoremediation of eutrophic waters using Eichhorniacrassipes in a controlled environment. Int J Environ Sci 2:241–246

Arnon DI (1951) Copper enzymes in isolated chlorophyll polyphenyloxidase in Beta vulgaris. Plant Physiol 24:1–15

Aziz A, Mobina NK (1999) Growth and morphology of S. polyrrhiza and S. punctata as affected by some environmental factors. Bangl J Bot 28:133–138

Böcher M, Fischer E, Ullrich-Eberius CI, Novacky A et al (1980) Effect of fusicoccin on the membrane potential, on the uptake of glucose and glycine, and on the ATP level in Lemnagibba G.1. Plant Sci Lett 18:215–200

Cheng J, Landesman L, Bergmann BA, Classen JJ, Howard JW, Yamamoto YT et al (2002) Nutrient removal from swine lagoon liquid by *Lemna minor* 8627. Transact ASAE 45:1003–1010

Cho KS, Kim BC, Heo WM, Kim DS et al (1991) Eutrophication of the major reservoirs in Korea Rep. Suwa Hydrobiol 7:21–29

Devlin RM, Witham (1986) Plant physiology, 4th edn. CBS Publishers and Distribution, New Delhi

Dospekhov BA (1984) Field experimentation. Mir Publications, Moscow

Edwards P (1985) Aquaculture: a component of low cost sanitation technology-integrates resource recovery. World Bank Technical Paper 36. Washington DC

Edwards P (1992) Reuse of human waste in aquaculture: a technical review. UNDP- World Bank water and sanitation programme. The World Bank Papar Washington DC

Fischer E, Lüttge U (1980) Membrane potential changes related to active transport of glycine in Lemnagibba G1. Plant Physiol 65:1004–1008

Fiske CH, Subbarow Y (1925) The calorimetric determination of phosphorus. J Biolog Chem 66:375–400

Ghosh C, Frijns J, Ghosh G, Lettinga G et al (1995) Water recycling through duckweed (*Lemna minor*) culture during post-summer months in European Climate. Ind J Environ Prot 15:677–684

Giese AC (1979) Cell Physiology, 5th edn. Toppan Company Ltd., Tokyo

Hillman WC (1961) The Lemnaceae of duckweed. A review of descriptive and experimental literature. Bot Rev 27:221–287

Jaiswal VS, Srivastava A (1987) Modifying effect of EDTA on toxicity and accumulation of cadmium by *Spirodela polyrrhiza* L. SP_{20}. In: Sharma MR, Gupta GK (eds) Recent advances in plant sciences. Dehradun, pp. 213–222

Jung KD, Lüttge U (1980) Amino acid uptake by Lemnagibba by a mechanism with affinity to neutral L- and D-amino acids. Planta 150:230–235

Khan FA, Ansari AA (2005) Eutrophication: an ecological vision. Bot Rev 71:449–482

Khitoliya RK (2004) Environmental pollution, management and control for sustainable development. S. Chand and Company Ltd., New Delhi, p 56

Kormondy EJ (1994) Concepts of ecology. Prentice Hall of India Pvt. Ltd., New Delhi

Korner S, Vermaat JE, Veenstra S et al (2003) The capacity of duckweed to treat waste water: ecological considerations for a sound design. J Environ Qual 32:1583–1590

Kulshrestha SK, Saxena R, George MP, Srivastava M, Tiwari A et al (1989) Phytoplankton of eutrophic Mansorovar reservoir of Bhopal. Int J Ecol Environ Sci 15:205–215

Kwang-Guk Park S, Ahn KH, Urchin CG (2003) Dynamics of nitrogen, phosphorus, algal biomass, and suspended solids in an artificial lentic ecosystem and significant implications of regional hydrology on trophic status. J Environl Biol 24:29–38

Lande A (1973) Byglandsfjorden. Primary production and other limnological features in an oligotrophic Norwegian lake. Hydrobiologia 41:335–344

Landolt E (1986) Biosystematic investigations in the family of duckweeds (Lemnaceae). Veroff Geobot Inst ETH Zurich 1:61–64

Lau S, Lane SN (2002a) Biological and chemical factors influencing shallow lake eutrophication: a long-term study. Sci Total Env 3:167–181

Lau SSS, Lane SN (2002b) Nutrient and grazing factors in relation to phytoplankton level in a eutrophic shallow lake: the effect of low macrophyte abundance. Water Res Oxford 36:3593–3601

Lindner RC (1944) Rapid analytical methods for some of the more inorganic constituents of plant tissues. Plant Physiol 19:76–89

Löppert H (1979) Evidence for electrogenic proton extrusion by subepidermal cells of *Lemnapaucicostata* 6746. Planta 144:311–315

Lüttge U, Jung KD, Ullrich-Eberius CI et al (1981) Evidence for amino acid-H^+ co transport in Lemnagibba given by effects of fusicoccin. Z Pflanzenphysiol 102:117–125

Mahadevan A, Sridhar R (1986) Hoagland solution. In: Methods in Physiological Plant Pathology, 3rd edn. Sivakami Publications, Madras

Misra SD, Bhargava SC, Bohra OP et al (1975) Diurnal variation in physico-chemical factors at Padmasagar reservoir during pre-monsoon period of the year 1974. Geobios 2:32–33

Neilson SL, Sand-Jensen K, Borum J, Geertz-Hansen O et al (2002) Phytoplankton, nutrients and transparency in Danish coastal waters. Estuaries 25:930–937

Novacky A, Fischer E, Ullrich-Eberius CI, Lüttge U, Ullrich WR et al (1978a) Membrane potential changes during transport of glycine as a neutral amino acid and nitrate in *Lemnagibba* G1. FEBS Lett 88:264–267

Novacky A, Ullrich-EberiusCI, Lüttge U (1978b) Membrane potential changes during transport of hexoses in *Lemnagibba* G1. Planta 138:263–270

Pandey BP (1997) Taxonomy of Angiosperms. S.Chand and Company, New Delhi
Rao CS (1998) Environmental pollution control engineering. New Age International (P) Ltd., New Delhi
Riis T, Sand JK (1998) Development of vegetation and environmental conditions in an oligotrophic Danish lake over 40 years. Freshwater Biol 40:123–134
Saad MAH (1973) Some limnological characteristics of the Nozh a Hydradrome, near Alexandria, Egypt. Hydrobiologia 41:477–500
Schindler DW (1971) Light, temperature and oxygen regimes of selected lakes in the experimental lakes area, North-Western Ontario. J Fish Res Bd Canada 28:157–169
Shen-Dong Sheng DS, Shen DS (2002) Study on limiting factors of water eutrophication of the network of rivers in plain. J Zhejiang Univ Agricul Life Sci 28:94–97
Srivastava A, Jaiswal VS (1989) Cadmium uptake by *Spirodela polyrrhiza* L. SP_{20}. Geobios16:237–240
Thornton FC, Schaedle M, Raynal DJ, Zipperer C et al (1986) Effects of aluminum on honeylocust (*Gleditsiatriacanthas* L.) seedlings in solution culture. J Exp Bot 37:775–785
Treshow M (1970) Environment and plant response. McGraw-Hill Book Company
Trivedi RK, Goel PK, Trisal CL et al (1987) Practical methods in ecology and environmental science. Enviro Media Publication, Karad (India)
Tsirtsis G, Karydis M (1997) Aquatic microcosms: a methodological approach for the quantification of eutrophication processes. Environ Monit Asses 48:193–215
Ullrich-Eberius CI, Novacky A, Lüttge U et al (1978) Active hexose uptake in Lemnagibba G1. Planta 139:149–153
Ullrich-Eberius CI, Novacky A, Fischer E, Lüttge U et al (1981) Relationship between energy dependent phosphate uptake and the electrical membrane potential in Lemnagibba G1. Plant Physiol 67:797–801
Van Dam H, Mertens A (1993) Diatoms on herbarium macrophytes as indicators for water quality. Hydrobiologia 269–270:437–445
Welch FB, Crook GD (1987) Lakes. In: Jordon WR, Gilpin ME, Aber JD (eds.). Restoration Ecology. Cambridge University Press, Cambridge, London, pp 109–129