EXPERIMENTAL RESULTS

Field Study

Physico-chemical analysis of rice field soil

Results in table (1) revealed that, the pH values were alkaline, lie within narrow limits 8.3 and 8.4, whereas electrical conductivity (E.C.) of soil ranged between 1117 and 1407 µ.mohs following thiobencarb and pendimethalin treatments, while with pretilachlor it did not exceed 1112 µ.mohs and in control 1150 µ.mohs. The content of organic carbon in all soil samples sustained 0.42, 0.48 and 0.48% with pretilachlor, pendimethalin and thiobencarb, respectively while in control the percentage was 0.57%. Calcium concentration in soil treated by pendimethalin increased to reach 22 ppm whereas the control was 17.5 ppm, however 15.4 ppm and 17 ppm were following pretilachlor and thiobencarb treatment, respectively. The concentration of magnesium, potassium and sodium in soils treated by herbicides was nearly equal to those of control. Chloride percentages in soil samples treated by herbicides were 0.007, 0.005 and 0.003% with pretilachlor, pendimethalin and thiobencarb, respectively but in untreated soil it was 0.004%. The percentage of carbonate, bicarbonate, nitrite and nitrate in soil treated by herbicides were in the range of control levels. Sulfate in soil treated by thiobencarb and pretilachlor amounted to 9.9 and 18.3 ppm being less than the control (31 ppm), whereas sulfate concentration in case of pendimethalin treatment was 42.1 ppm. Concentration of phosphate in soils treated by thiobencarb, pendimethalin and pretilachlor were 2.0, 3.7 and 1.3 ppm, respectively which appeared to be less than the control (4.2 ppm). Silicate level in soils treated by herbicides were within the control level. Ammonia content in treated soils exceeded that registered for control experiment, except thiobencarb treatment which was equal to control value.

Algal flora of rice fields

Soil samples collectively harboured 30 algal species (Tables, 2 & 3). Out of these, 15 species belong to Cyanophyta, 11 to Chlorophyta, 3 to Bacillariophyta and one to Xanthophyta Fig (1).

Cyanophyta species represented about 50% of total algal flora of all soil samples and these were dominated by *Tolypothrix distorata, Anabaena constricta, Oscillatoria trebriformis and Nostoc paludosum.* Chlorophyta species constituted 36.7% of the total algal flora recorded from soil samples and were represented by unicellular, colonial and filamentous forms. The most dominant species were *Chlamydomonas reinhardii, Chlorella vulgaris and Tetracystis isobilaterallis.* Bacillariophyta species *Navicula cuspidata, Hantzschia virgata* and *Nizschia filiformis* constituted 10% of the recorded algal flora from soil samples. Xanthophyta was represented only by *Tribonema utriculosm*. It was revealed that members of blue green and coccoid green algae represented the predominant forms, which has been found to have very high level of tolerance against many agricultural chemicals.

Response of algal flora to herbicides at Qalubia rice field during 1994

Effect of the three herbicides (thiobencarb, pendimethalin and pretilachlor) used singly and in combinations at its recommended doses on algal flora of Qalubia rice field revealed that algal community of the experimented paddy rice field constituted of 30 species from four divisions. Thirteen species were of scanty counts, so they were excluded: *Cladophora crispata, Klebsormidium flaccidium, Protococcus viridious, Pseudoshizomeris caudata,* and *Ulothrix cylindricum* from Chlorophyta; *Anabaena helicoda, Anabaena torulosa, Calothrix braunii, Dactylococcopsis raphidioides* and *Oscillatoria acuminata* from Cyanophyta; *Navicula cuspidata, Hantzschia virgata,* and *Nitzschia amphibia* from Bacillariophyta. The remaining seventeen species were responded to the applied herbicides quite differently as the following:

A- Tolerance response: table (6) shows that six species tolerated the application of the three herbicides when applied singly or in combinations. These were *Anabaena constricta, Nostoc microscopicum, Protosiphon botryoides, Tetracystis isobilateralis, Tolypothrix distorta* and *Chlamydomonas reinhardii.*

B- Stimulatory response: the data given in table (7) show that three of the identified algae exhibited different stimulatory response to the application of the three herbicides as follows: *Oscillatoria trebriformis* showed stimulatory response to each of the three herbicides when applied singly or in combinations. *Anabaena contorta* showed stimulatory response synergized lately by the application of pretilachlor in combination with either thiobencarb or pendimethalin but it was completely antagonized by the combinations of the three herbicides all together. *Chlorella vulgaris* exhibited stimulatory response to the application of pendimethalin when applied singly; however, when it was applied as only thiobencarb or pretilachlor or both together, the stimulatory response weakened indicating antagonistic effect for thiobencarb and pretilachlor to the stimulatory effect of pendimethalin.

C- Inhibitory response: data in table (8) revealed that the inhibitory response to the application of the three herbicides was exhibited mainly by contribution of eight species which are of rare counts. However, such inhibitory response was of different types as follows: *Anabaenopsis circularis, Chlorella ellipsoidea* and *Anabaena spiroides* were inhibited by any combination of the three herbicides. *Tribonema utriculosum* and *Chlorococcum humicola* exhibited slight growth inhibition due to single application of the herbicides, but any combination of these herbicides lead to effective inhibition on the growth of these two algae. *Anabaena variabilis*, growth decreased as a response to thiobencarb and pendimethalin but not to pretilachlor, however, growth of this alga was inhibited when these herbicides applied in combination. *Nostoc paludosum* exhibited early inhibitory response to the combination of pretilachlor with thiobencarb and pendimethalin. *Oscillatoria limosa* growth decreased as a response to the application of thiobencarb. Such inhibition prolonged to the 30th day of experimentation. It showed early slight inhibition to pendimethalin through the first week only but tolerated pretilachlor. Herbicides combination had no clear effect.

Table (1): Average values of physico-chemical characters of Qalubia rice field soils treated and untreated by herbicides (thiobencarb, pendimethalin and pretilachlor) during summer 1994.

Treatment / Soil analysis	Control	Thiobencarb	Pendimethalin	Pretilachlor
pH	8.4	8.4	8.3	8.3
E.C. μ mhos	1150	1117	1407	1112
Ca^{++} ppm	17.5	17	22	15.4
Mg^{++} ppm	1.9	1.9	1.6	1.9
Na^{+} ppm	45	43.5	44.2	42.5
K^{+} ppm	15.9	15.8	13.9	13.4
%Cl^{-}	0.004	0.003	0.005	0.007
%$HCO3^{-}$	0.08	0.06	0.07	0.06
%$CO3^{--}$	0.003	0.004	0.002	0.002
%Organic Carbon	0.57	0.48	0.48	0.42
Nitrite ppm	5.9	4.9	5.9	7.6
Nitrate ppm	120	115	118	122
Sulfate ppm	31	9.9	42.1	18.3
Phosphate ppm	4.2	2	3.7	1.3
Silicate ppm	7.33	7.68	7.38	6.53
Ammonia ppm	0.61	0.60	1.40	1.1

Table (2): A list of the recorded algal species, No. of cases of isolation and frequency of occurrence in treated and untreated soil samples collected from rice field at Qalubia applying thiobencarb, pendimethalin and pretilachlor herbicides singly during summer 1994.
(4 replicates in each treatment)

Collection intervals	One day				One week				Two weeks				One months				Two months				Three months			
Soil Sample / Algal taxa	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Chlorophyta																								
Chlamydomonas reinhardii Dang	H	H	H	H	H	L	R	H	H	H	H	H	H	H	H	H	M	H	M	H	H	H	H	H
Chlorella ellipsoidea Cerneck	-	-	-	-	L	L	R	L	-	-	R	-	-	R	-	R	-	-	-	-	-	-	-	-
Chlorella vulgaris Beyerinck	R	L	M	R	L	R	M	-	R	R	R	R	L	L	R	R	R	R	R	R	-	R	R	R
Chlorococcum humicola Naeg.	R	R	R	R	R	R	R	R	-	-	-	R	-	R	-	-	R	-	-	-	R	R	-	R
Cladophora crispata Roth	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Klebsormidium flaccidium Kuetz.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	-	-
Protosiphon botryoides Kuetz.	R	R	R	-	-	-	-	-	-	R	-	R	-	-	R	R	R	R	-	-	R	R	-	R
Protococcus viridius Agardh.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-
Pseudoshizomeris caudata Fott	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	R	-	-	-	-	-	-	-	-
Tetracystis isobilateralis Link	R	-	R	R	L	L	R	L	M	M	L	L	L	L	R	L	R	R	L	L	L	M	-	R
Ulothrix cylindricum Prescott	-	-	-	-	-	-	-	-	-	-	-	-	L	-	-	-	-	-	-	-	-	-	-	-
Number of species	5	4	6	4	5	5	5	4	3	4	4	5	4	5	5	7	5	4	3	3	5	6	2	5
Cyanophyta																								
Anabaena constricta Geitler	R	R	L	R	R	R	L	L	R	R	-	L	L	L	L	R	L	L	R	R	R	L	L	R
Anabaena contorta Beckm	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	R	L	L	R
Anabaena helicoda Bernard	-	-	-	-	-	-	-	-	R	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena torulosa Lagerheim	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena spiroides Klebahn	R	-	R	-	R	L	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena variabilis Kuetz.	R	-	-	R	R	-	-	R	R	R	R	-	-	-	-	-	R	R	-	R	-	-	-	-
Anabaenopsis circularis Miller	-	-	-	-	R	R	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Rank of algal occurrence:

H = high < 50 colonies
M = moderate 6 – 15 colonies
L = low 2 –5 colonies
R = rare one colony
- = not detected

Table 2 (cont.)

Collection intervals	One day				One week				Two weeks				One months				Two months				Three months			
Soil sample / Algal taxa	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
Calothrix brunii Prescott	-	-	-	-	L	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dactylococcopsis raphidioides Han.	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nostoc microscopicum Fremy	-	-	-	-	R	R	-	R	-	R	R	R	-	-	R	R	R	L	R	R	R	-	R	R
Nostoc paludosum Kuetz.	R	R	R	R	L	R	R	R	-	-	R	R	-	-	R	-	-	-	-	R	R	R	R	R
Oscillatoria limosa Agardh.	R	-	-	R	R	-	R	-	R	-	R	R	-	-	-	-	R	R	R	R	R	R	R	R
Oscillatoria acuminata Gom.	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oscillatoria trebriformis Agardh.	L	M	L	M	R	L	L	R	R	R	R	-	-	R	-	-	L	R	-	R	L	R	R	R
Tolypothrix distorta Kuetz.	L	R	L	M	R	R	R	R	R	L	R	R	R	R	R	R	L	L	R	L	-	-	R	R
Number of species	7	4	5	6	11	9	8	8	6	6	7	6	2	3	4	3	6	6	4	7	7	6	7	7
Bacillariophyta																								
Navicula cuspidata Kuetz.	R	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	R	-	-	L	-	-	-
Hantzschia virgata Round	R	-	R	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nitzschia amphibia Var.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Number of species	2	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
Xanthophyta																								
Tribonema utriculosum Kuetz.	R	-	-	-	R	R	R	R	-	R	R	R	-	-	R	R	R	-	R	-	-	-	-	-
Number of species	1	0	0	0	1	1	1	1	0	1	1	1	0	0	1	1	1	0	1	0	0	0	0	0
Total number of species	15	8	12	11	17	15	15	13	9	11	12	12	6	8	10	11	12	11	8	10	14	12	9	12

Herbicide treatment:
1=Control; 2=Thiobencarb; 3=Pendimethalin; 4=Pretilachlor

Table (3): A list of the recorded algal species, No. of cases of isolation and frequency of occurrence in treated soil samples collected from rice field at Qalubia applying thiobencarb, pendimethalin and pretilachlor herbicides in combination during summer 1994.
(4 replicates in each treatment)

Collection intervals	One day				One week				Two weeks				One months				Two months				Three months			
Soil sample / Algal taxa	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8
Chlorophyta																								
Chlamydomonas reinhardii Dang	M	H	L	H	M	M	M	H	H	H	H	L	H	H	H	L	L	L	L	H	H	L	L	H
Chlorella ellipsoidea Cerneck	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-
Chlorella vulgaris Beyerinck	R	L	R	L	R	R	R	R	R	R	R	-	R	R	R	R	R	L	R	R	R	R	R	R
Chlorococcum humicola Naeg.	-	-	-	-	-	R	-	-	R	-	R	-	-	-	R	R	L	-	-	R	R	-	-	-
Cladophora crispata Roth	-	-	-	-	R	-	-	R	R	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-
Klebsormidium flaccidium Kuetz.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Protosiphon botryoides Kuetz.	-	-	-	R	R	R	R	R	R	-	R	-	-	-	-	-	-	-	-	-	R	R	R	L
Protococcus viridius Agardh.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Pseudoshizomeris caudata Fott	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Tetracystis isobilateralis Link	L	R	R	R	R	L	R	R	-	-	R	R	-	R	L	R	R	-	-	R	-	-	R	-
Ulothrix cylindricum Prescott	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Number of species	3	3	3	5	5	5	4	5	5	2	5	2	3	3	4	4	3	2	2	5	4	4	4	3
Cyanophyta																								
Anabaena constricta Geiller	R	R	R	R	R	R	R	R	M	R	R	R	R	R	R	R	-	-	-	-	R	R	L	L
Anabaena contorta Beckm	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-	R	H	H	-	R	H	H	-
Anabaena helicoda Bernard	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena torulosa Lagerheim	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena spiroides Klebahn	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Anabaena variabilis Kuetz.	-	R	-	-	-	-	-	L	-	-	-	R	-	-	-	-	-	-	-	-	-	R	-	R
Anabaenopsis circularis Miller	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-

Rank of algal occurrence:

H = high < 50 colonies
M = moderate 6 – 15 colonies
L = low 2 –5 colonies
R = rare one colony
- = not detected

Table 3 (cont.)

Collection intervals	One day				One week				Two weeks				One months				Two months				Three months			
Algal taxa / Soil sample	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8	5	6	7	8
Calothrix brunii Prescott	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Dactylococcopsis raphidioides Han.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Nostoc microscopicum Fremy	R	-	R	-	R	-	-	R	-	-	-	R	R	R	R	R	R	-	R	-	-	R	R	R
Nostoc paludosum Kuetz.	R	-	-	-	R	-	-	R	-	R	R	R	R	-	-	-	R	L	R	R	R	R	R	R
Oscillatoria limosa Agardh.	-	R	R	R	H	R	R	L	L	R	R	R	R	R	-	R	R	R	R	R	R	R	R	R
Oscillatoria acuminata Gom	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
Oscillatoria trebriformis Agardh.	M	M	L	M	M	M	L	R	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M	M
Tolypothrix distorta Kuetz.	-	-	-	-	R	R	R	L	R	R	L	R	L	L	R	-	R	R	R	R	L	R	R	R
Number of species	4	4	4	3	6	4	4	6	4	6	6	6	6	5	4	4	6	5	6	4	6	8	7	7
Bacillariophyta																								
Navicula cuspidata Kuetz.	-	-	-	R	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Hantzschia virgata Round	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-	-	-	-
Nitzschia amphibia Var.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	-	-
Number of species	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0
Xanthophyta																								
Tribonema utriculosum Kuetz.	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	R	-	R	-	-	-	-	-
Number of species	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0
Total number of species	7	7	7	9	11	9	8	11	9	8	11	8	9	8	8	8	10	8	9	9	10	12	11	10

Herbicide treatment:

5=Thiobencarb+Pendimethalin; 6=Thiobencarb+Pretilachlor; 7=Pendimethalin+Pretilachlor; 8=Thiobencarb+ Pendimethalin+ Pretilachlor

Table (4): Number of recorded algal species in soil collected from Qalubia rice field treated and untreated by the different herbicides during summer 1994.

Collection intervals	Soil Sample No.	Chlorophyta	Cyanophyta	Bacillariophyta	Xanthophyta	Total number of species
One Day	1	5	7	2	1	15
	2	4	4	-	-	8
	3	6	5	1	-	12
	4	4	6	1	-	11
One week	1	5	11	-	1	17
	2	5	9	-	1	15
	3	5	8	1	1	15
	4	4	8	-	1	13
Two weeks	1	3	6	-	-	9
	2	4	6	-	1	11
	3	4	7	-	1	12
	4	5	6	-	1	12
One month	1	4	2	-	-	6
	2	5	3	-	-	8
	3	5	4	-	1	10
	4	7	3	-	1	11
Two months	1	5	6	-	1	12
	2	4	6	1	-	11
	3	3	4	-	1	8
	4	3	7	-	-	10
Three months	1	5	7	2	-	14
	2	6	6	-	-	12
	3	2	7	-	-	9
	4	5	7	-	-	12

Herbicide treatment:
1=Control; 2=Thiobencarb; 3=Pendimethalin; 4=Pretilachlor

Table (5): Number of recorded algal species in soil collected from Qalubia rice field treated by combination of thiobencarb, pendimethalin and pretilachlor herbicides during summer 1994.

Collection intervals	Soil Sample No.	Chlorophyta	Cyanophyta	Bacillariophyta	Xanthophyta	Total number of species
One Day	5	3	4	-	-	7
	6	3	4	-	-	7
	7	3	4	-	-	7
	8	5	3	1	-	9
One week	5	5	6	-	-	11
	6	5	4	-	-	9
	7	4	4	-	-	8
	8	5	6	-	-	11
Two weeks	5	5	4	-	-	9
	6	2	6	-	-	8
	7	5	6	-	-	11
	8	2	6	-	-	8
One month	5	3	6	-	-	9
	6	3	5	-	-	8
	7	4	4	-	-	8
	8	4	4	-	-	8
Two months	5	3	6	-	1	10
	6	2	5	1	-	8
	7	2	6	-	1	9
	8	5	4	-	-	9
Three months	5	4	6	2	-	12
	6	4	8	-	-	12
	7	4	7	-	-	11
	8	3	7	-	-	10

Herbicide treatment:

5=Thiobencarb+Pendimethalin; 6=Thiobencarb+Pretilachlor; 7=Pendimethalin+Pretilachlor; 8=Thiobencarb+ Pendimethalin+ Pretilachlor

Table (6): Tolerance response of some of the recorded algal species to herbicides application at Qalubia rice field during summer 1994.

Algal species	Period (days)	Control	Herbicides treatments						
			Singly			Combination			
			1	2	3	1+2	1+3	2+3	1+2+3
Anabaena constricta	1	R	R	L	R	R	R	R	R
	7	R	R	L	L	R	R	R	R
	14	R	R	-	L	M	R	R	R
	30	L	L	L	R	R	R	R	R
	60	L	L	R	R	-	-	-	-
	90	R	L	L	R	R	R	L	L
Nostoc microscopicum	1	-	-	-	-	R	-	R	-
	7	R	R	-	R	R	-	-	R
	14	-	R	R	R	-	-	-	R
	30	-	-	R	R	R	R	R	R
	60	R	L	R	R	R	-	R	-
	90	R	-	R	R	-	R	R	R
Protosiphon botryoides	1	R	R	R	-	-	-	-	R
	7	-	-	-	-	R	-	R	R
	14	-	R	-	R	R	-	R	-
	30	-	-	R	R	-	-	-	-
	60	R	R	-	-	-	R	-	-
	90	R	R	-	R	R	R	R	L
Tetracystis isobilateralis	1	R	-	R	R	L	R	R	R
	7	L	L	R	L	R	L	R	R
	14	M	M	L	L	-	-	R	R
	30	L	L	R	L	-	R	L	R
	60	R	R	L	L	R	-	-	R
	90	L	M	-	R	-	-	R	-
Tolypothrix Distorta	1	L	R	L	M	-	-	-	-
	7	R	R	R	R	R	R	R	L
	14	R	L	R	R	R	R	L	R
	30	R	R	R	R	L	L	R	-
	60	L	L	R	L	R	R	R	R
	90	-	-	R	R	L	R	R	R
Chlamydomonas reinhardii	1	H	H	H	H	M	H	L	H
	7	H	L	R	H	M	M	M	H
	14	H	H	H	H	H	H	H	L
	30	H	H	H	H	H	H	H	L
	60	M	H	M	H	L	L	L	H
	90	H	H	H	H	H	H	H	H

Herbicide treatment:
1=Thiobencarb; 2=Pendimethalin; 3=Pretilachlor

Rank of algal occurrence:

H = high < 50 colonies
M = moderate 6 – 15 colonies
L = low 2 –5 colonies
R = rare one colony
-= not detected

Table (7): Stimulatory response of some of the recorded algal species to herbicides application at Qalubia rice field during summer 1994.

Algal species	Period (days)	Control	Herbicides treatment						
			Singly			Combination			
			1	2	3	1+2	1+3	2+3	1+2+3
Oscillatoria trebriformis	1	L	M	L	M	M	M	L	M
	7	R	L	L	R	M	M	L	R
	14	R	R	R	-	M	M	M	M
	30	-	R	-	-	M	M	M	M
	60	L	R	-	R	M	M	M	M
	90	L	R	R	R	M	M	M	M
Anabaena contorta	1	-	-	-	-	-	-	-	-
	7	-	-	-	-	-	-	-	-
	14	-	-	-	R	-	R	-	-
	30	-	-	-	-	-	-	-	-
	60	-	-	-	-	R	H	H	-
	90	R	L	L	R	R	H	H	-
Chlorella vulgaris	1	R	L	M	R	R	L	R	L
	7	L	R	M	-	R	R	R	R
	14	R	R	R	R	R	R	R	-
	30	L	L	R	R	R	R	R	R
	60	R	R	R	R	R	L	R	R
	90	-	R	R	R	R	R	R	R

Herbicide treatment:
1=Thiobencarb; 2=Pendimethalin; 3=Pretilachlor

Rank of algal occurrence:

H = high < 50 colonies
M = moderate 6 – 15 colonies
L = low 2 –5 colonies
R = rare one colony
- = not detected

Table (8): Inhibitory response of some of the recorded algal species to herbicides application at Qalubia rice field during summer 1994.

Algal species	Period (days)	Control	Herbicides treatments						
			Singly			Combination			
			1	2	3	1+2	1+3	2+3	1+2+3
Anabaenopsis circularis	1	-	-	-	-	-	-	-	-
	7	R	R	R	R	-	-	-	-
	14	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-
	60	-	-	-	-	-	-	-	-
	90	-	-	-	-	-	-	-	-
Chlorella ellipsoidea	1	-	-	-	-	-	-	-	-
	7	L	L	R	L	-	-	-	-
	14	-	-	R	-	-	-	-	-
	30	-	R	-	R	-	-	-	-
	60	-	-	-	-	-	-	-	-
	90	-	-	-	-	-	-	-	-
Anabaena spiroides	1	R	-	R	-	-	-	-	-
	7	R	L	R	R	-	-	-	-
	14	-	-	-	-	-	-	-	-
	30	-	-	-	-	-	-	-	-
	60	-	-	-	-	-	-	-	-
	90	-	-	-	-	-	-	-	-
Tribonema utriculosum	1	R	-	-	-	-	-	-	-
	7	R	R	R	R	-	-	-	-
	14	-	R	R	R	-	-	-	-
	30	-	-	R	R	-	-	-	-
	60	R	-	R	-	R	-	R	-
	90	-	-	-	-	-	-	-	-
Chlorococcum humicola	1	R	R	R	R	-	-	-	-
	7	R	R	R	R	-	R	-	-
	14	-	-	-	R	R	-	R	-
	30	-	R	-	-	-	-	R	R
	60	R	-	-	-	L	-	-	R
	90	R	R	-	R	R	-	-	-
Anabaena variabils	1	R	-	-	R	-	R	-	-
	7	R	-	-	R	-	-	-	L
	14	R	R	R	-	-	-	-	R
	30	-	-	-	-	-	-	-	-
	60	R	R	-	R	-	-	-	-
	90	-	-	-	-	-	R	-	R
Nostoc paludosum	1	R	R	R	R	R	-	-	-
	7	L	R	R	R	R	-	-	R
	14	-	-	R	R	-	R	R	R
	30	-	-	R	-	R	-	-	-
	60	-	-	-	R	R	L	R	R
	90	R	R	R	R	R	R	R	R
Oscillatoria limosa	1	R	-	-	R	-	R	R	R
	7	R	-	R	-	H	R	R	L
	14	R	-	R	R	L	R	R	R
	30	-	-	-	-	R	R	-	R
	60	R	R	R	R	R	R	R	R
	90	R	R	R	R	R	R	R	R

Herbicide treatment:
1=Thiobencarb; 2=Pendimethalin; 3=Pretilachlor

Rank of algal occurrence:
H = high < 50 colonies
M = moderate 6 – 15 colonies
L = low 2 –5 colonies
R = rare one colony
- = not detected

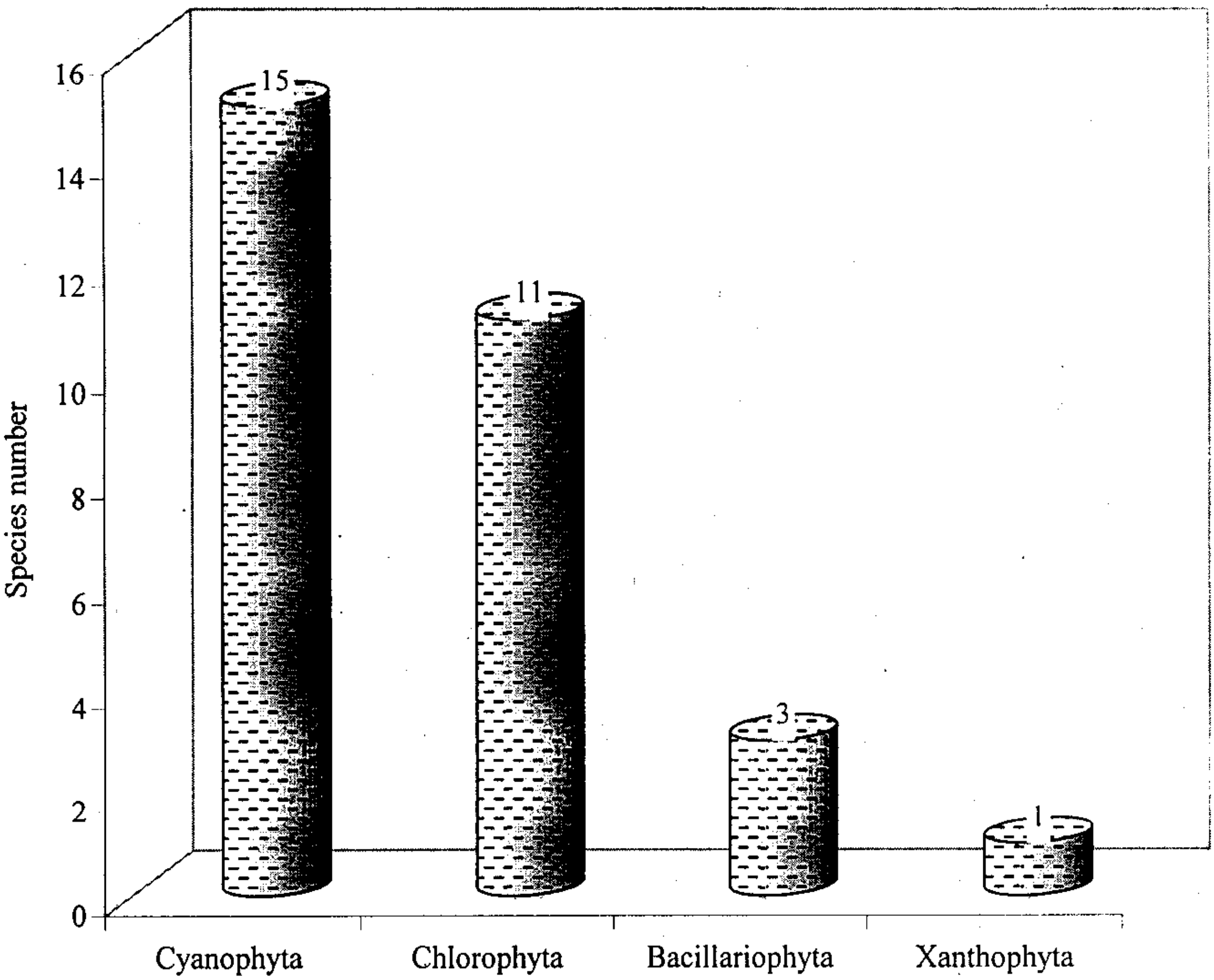

Fig. (1): Algal flora of an Egyptian rice field at Qalubia during summer 1994.

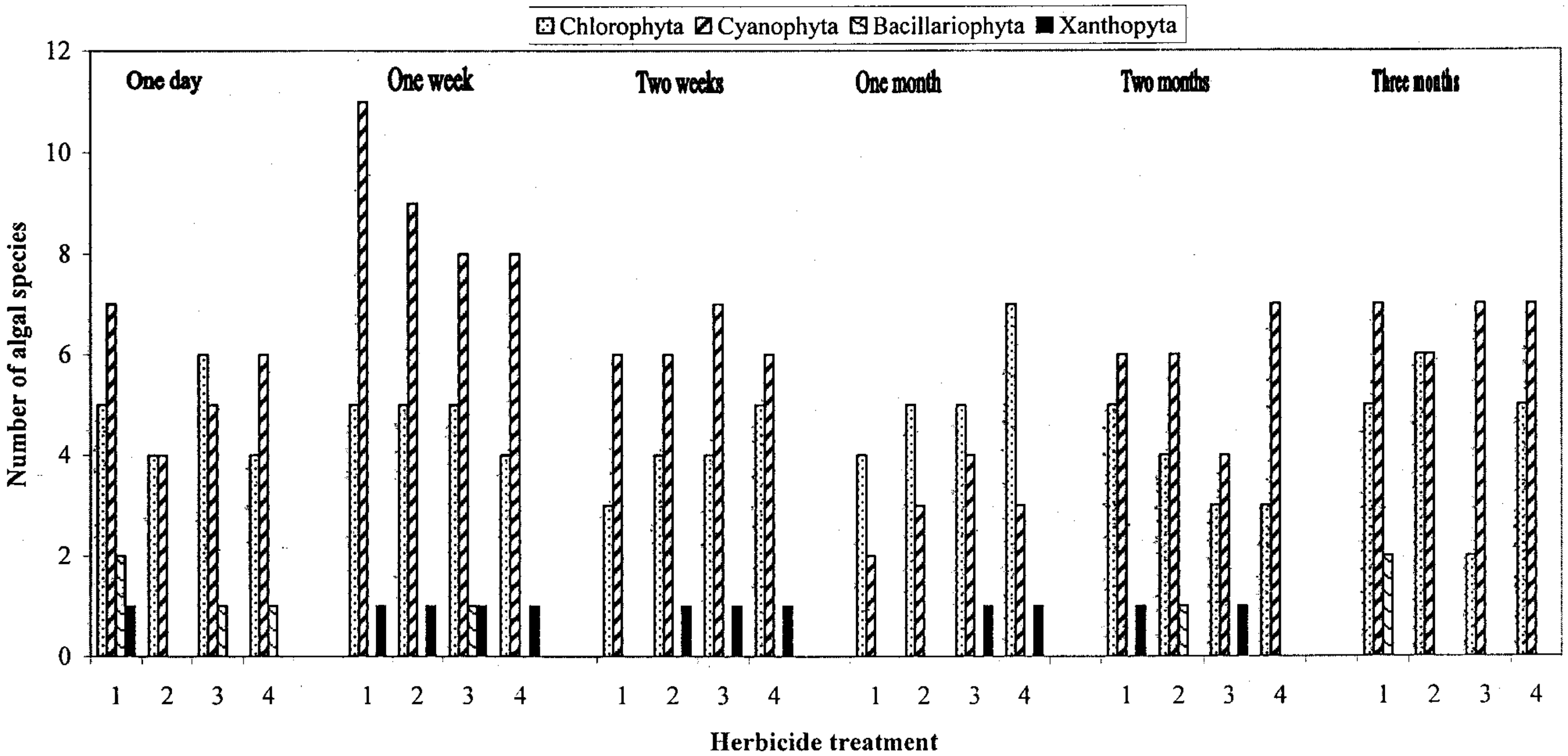

Fig (2): Effect of herbicide application on number of algal species recorded from Qalubia rice field during summer 1994.
Herbicide treatment: (1= control; 2=thiobencarb; 3= pendimethalin; 4= pretilachlor).

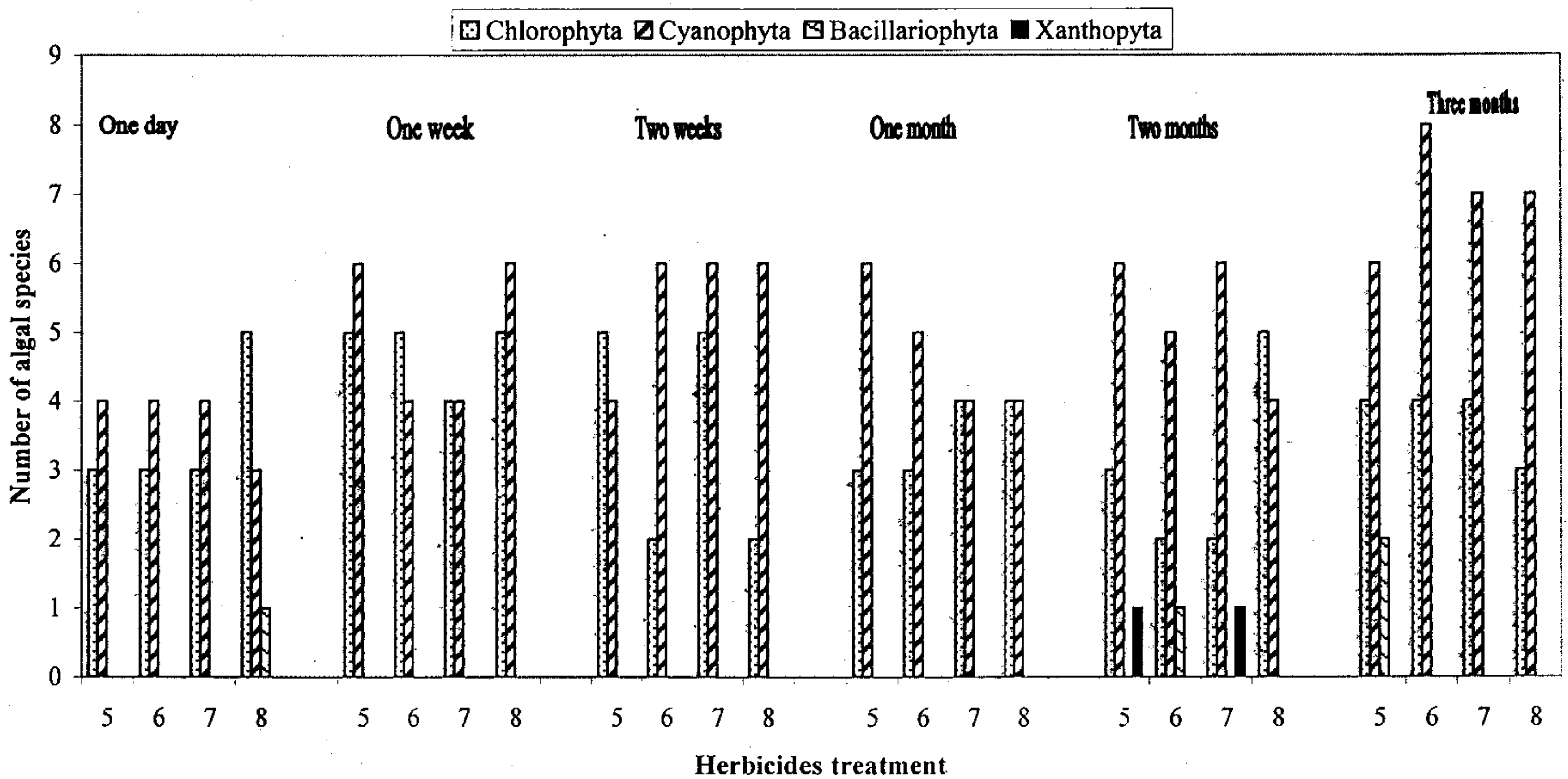

Fig (3): Effect of herbicide application on number of algal species recorded from Qalubia rice field during summer 1994. Herbicide treatment: 5=thiobencarb+pendimethalin; 6=thiobencarb+pretilachlor; 7=pendimethalin+pretilachlor; 8=thioben.+pendi.+pretil.

I- Herbicides effect on growth and recovery of algae

1- Effect of thiobencarb on *Protosiphon* and its subsequent recovery

One-way ANOVA revealed a significant effect of thiobencarb on *Protosiphon botryoides* incubated for 16 days in standard BBM for all growth and physiological variables except carbohydrate content and gross photosynthesis normalized to chlorophyll *a* (P_m^{Chl}) (Table, 10). Specific growth rate (μ, days 2-8) significantly increased at low thiobencarb treatment, but significantly decreased at the highest concentration. Turbidity, cell number, Chl *a* and DW yields significantly decreased with increasing thiobencarb concentration as presented in table (10) and illustrated in (Fig. 4). Chl *a* (mg g^{-1} DW) decreased significantly with increasing thiobencarb concentration. Dry weight normalized protein, but not carbohydrate content, decreased significantly at the highest thiobencarb concentration. The ratio of variable fluorescence to maximal fluorescence (F_v/F_m), which is a reliable indicator of the photochemical efficiency of photosystem II decreased slightly but significantly in the presence of thiobencarb. Gross photosynthesis normalized to chlorophyll *a* (P_m^{Chl}) was not significantly affected by thiobencarb, whereas dark respiration normalized to chlorophyll *a* (R_d^{Chl}) increased significantly at the highest thiobencarb concentration compared to the control.

During the recovery period after resuspension in thiobencarb-free medium, specific growth rate (μ), turbidity, cell number, Chl *a* and DW yields, and physiological measurements of *Protosiphon botryoides* were increased to be in the range of control values, regardless of prior thiobencarb exposure. The only exception was that cells recovered from 2 mg L^{-1} thiobencarb had significantly higher protein content than control.

Table (9): Effect of thiobencarb on *Protosiphon botryoides* and its subsequent recovery. Means ± SD (n=3)

		Initial treatment				Recovery			
Time		Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}	Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}
2 days	Turbidity (A_{750})	0.03±0.00	0.02±0.02	0.02±0.00	0.02±0.00	0.06±0.01	0.04±0.00	0.04±0.00	0.04±0.00
4 days		0.06±0.00	0.04±0.03	0.03±0.01	0.02±0.00	0.10±0.03	0.08±0.00	0.07±0.00	0.08±0.00
6 days		0.09±0.01	0.07±0.04	0.04±0.01	0.03±0.00	0.14±0.03	0.12±0.02	0.12±0.01	0.12±0.01
8 days		0.12±0.01	0.10±0.05	0.05±0.00	0.03±0.00	0.21±0.04	0.18±0.02	0.18±0.02	0.17±0.00
12 days		0.21±0.02	0.16±0.09	0.09±0.01	0.05±0.01	0.39±0.07	0.34±0.05	0.35±0.02	0.32±0.02
16 days		0.28±0.03	0.20±0.14	0.14±0.03	0.07±0.01	0.55±0.07	0.51±0.07	0.53±0.02	0.50±0.01
2 days	Cell number x 10^4 (cell ml^{-1})	39±15	26±7	21±7	15±4	45±14	35±10	31±4	32±6
4 days		49±4	45±22	27±5	22±2	74±15	57±17	44±6	50±4
6 days		78±8	73±19	50±10	30±3	128±10	128±33	95±9	100±28
8 days		130±26	92±19	65±22	37±4	148±13	150±15	153±32	133±38
12 days		242±63	228±37	118±25	47±12	322±58	355±41	315±41	305±28
16 days		490±79	417±80	195±38	115±41	347±90	405±13	383±29	325±25
2 days	Chlorophyll *a* (mg L^{-1})	0.45±0.05	0.26±0.07	0.18±0.02	0.11±0.01	0.54±0.15	0.40±0.08	0.37±0.05	0.37±0.01
4 days		0.70±0.07	0.38±0.10	0.26±0.06	0.13±0.01	0.81±0.21	0.70±0.11	0.65±0.05	0.73±0.02
6 days		0.77±0.02	0.66±0.16	0.30±0.04	0.14±0.02	1.08±0.32	0.83±0.08	0.74±0.01	0.84±0.06
8 days		1.15±0.11	0.89±0.13	0.42±0.09	0.16±0.01	1.42±0.36	1.19±0.12	1.21±0.07	1.21±0.04
12 days		1.40±0.13	1.07±0.10	0.67±0.09	0.28±0.04	2.40±0.47	2.34±0.43	2.40±0.02	2.08±0.35
16 days		1.81±0.15	1.28±0.13	0.86±0.14	0.35±0.03	2.85±0.39	2.55±0.46	2.73±0.27	2.55±0.04

Table (10): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of thiobencarb treatment and recovery period. Means ± SD (n=3). Results of One-way ANOVA and Dunnett's one-sided comparison of treatments to controls indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

Thiobencarb mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times 10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* (mg g^{-1} DW)	Protein (mg g^{-1} DW)	Carbo. (mg g^{-1} DW)	F_v/F_m	Gross P_m (mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)	R_d (mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)
Control	0.14±0.02	0.28±0.02	490±79	1.81±0.15	181±15	10.0±0.7	88±4	175±18	0.72±0.02	304±36	-43±16
1.0	0.22±0.02**	0.19±0.00***	417±80	1.31±0.08***	144±16*	9.2±1.4	75±23	178±158	0.66±0.01**	254±37	-50±11
2.0	0.13±0.03	0.13±0.03***	195±38***	0.93±0.15***	95±14***	9.7±0.3	77±3	140±59	0.66±0.02**	219±26	-54±20
3.0	0.06±0.02**	0.07±0.01***	115±41***	0.38±0.04***	61±5***	6.3±0.1***	55±5*	196±97	0.68±0.01*	320±95	-108±8***
One-way ANOVA	***	***	***	***	***	***	*	NS	**	NS	**
Recovery											
Control	0.16±0.03	0.55±0.07	388±54	2.85± 0.39	438±19	6.5±1.1	40±5	97±29	0.80±0.01	195±51	-44±46
1.0	0.17±0.04	0.51±0.07	433±42	2.55± 0.46	427±64	6.0±0.4	50±9	111±28	0.80±0.01	196±10	-17±6
2.0	0.18±0.01	0.53±0.02	443±60	2.73± 0.27	427±64	6.6±1.5	63±13 *	83±8	0.81±0.01	184±4	-20±12
3.0	0.18±0.00	0.50±0.01	360±33	2.55±0.04	433±99	6.1±1.5	44±11	58±20	0.81±0.01	225±23	-21±28
One-way ANOVA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(μ) Specific growth rate over days 2-8

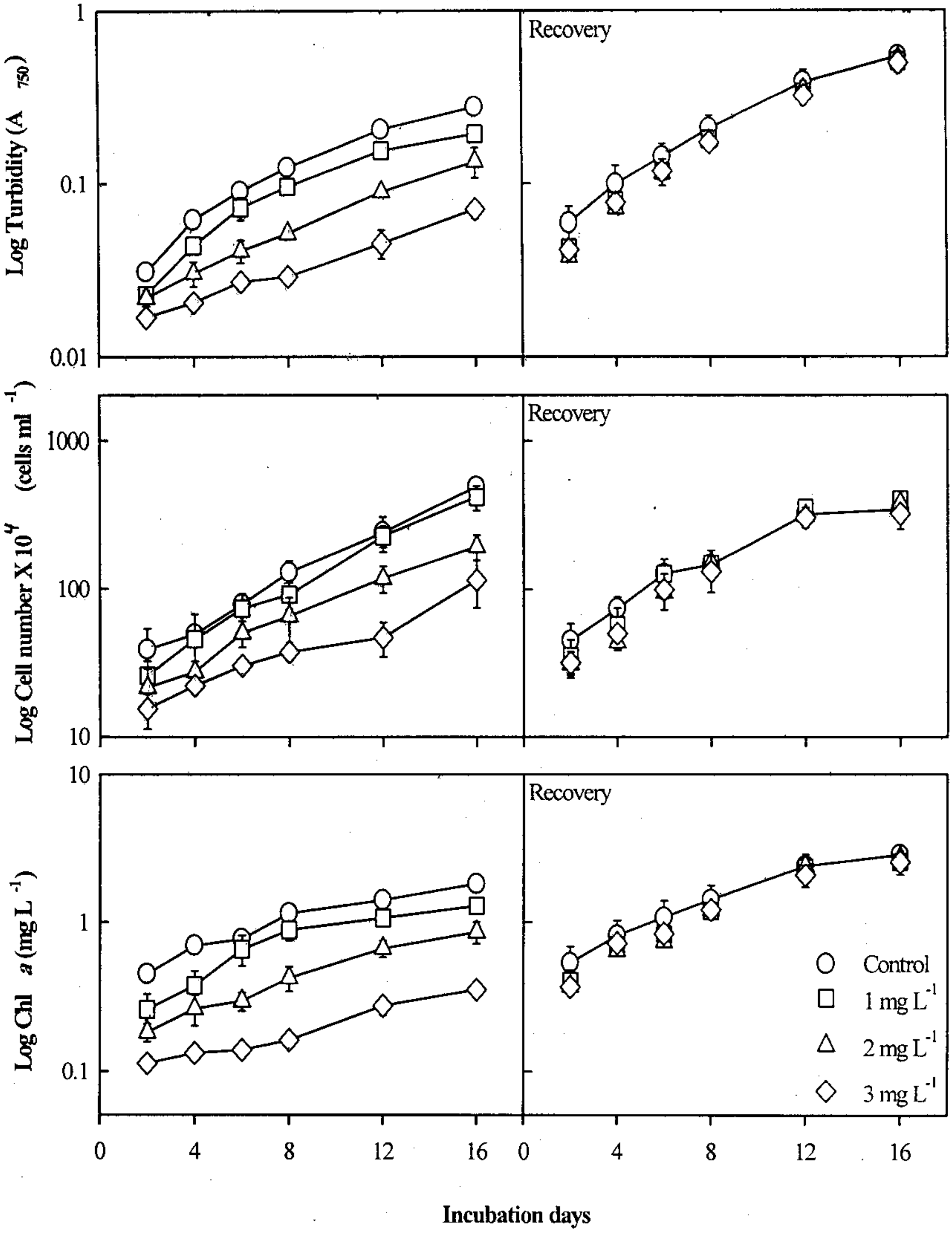

Fig. (4): Effect of thiobencarb on turbidity, cell number and chlorophyll *a* of *Protosiphon botryoides* and its recovery. Means ± SD (n=3).

2- Effect of thiobencarb on *Anabaena* and its subsequent recovery

One-way ANOVA application on growth and physiological measurements of *Anabaena variabilis* incubated for 10 days in standard BG-11 medium containing different thiobencarb concentrations revealed a significant effect of thiobencarb on *Anabaena variabilis* for all growth and physiological variables, except gross photosynthesis normalized to chlorophyll *a* (P_m^{Chl}) and dark respiration normalized to chlorophyll *a* (R_d^{Chl}) as shown in table (12). Specific growth rate (μ, days 2-6) significantly decreased at 1 and 2 mg L^{-1}, but not 3 mg L^{-1} thiobencarb. Turbidity, Chl *a* and DW yields significantly decreased with increasing thiobencarb concentration as presented in table (12) and illustrated in Fig. (5). Chl *a* (mg g^{-1} DW) decreased significantly at 1 mg L^{-1} thiobencarb, whereas it was not significantly affected at the higher concentrations. Dry weight normalized protein decreased significantly in the presence of thiobencarb, whereas carbohydrate content significantly increased at 2 and 3 mg L^{-1} thiobencarb. Variable fluorescence to maximal fluorescence (F_v/F_m), which is an indicator of the photochemical efficiency of photosystem II decreased slightly but significantly at 3 mg L^{-1} thiobencarb. Gross P_m^{Chl} increased significantly at 2 mg L^{-1} compared to control, whereas R_d^{Chl} was not significantly affected by thiobencarb. In recovery experiment previously thiobencarb exposed *Anabaena* cells in thiobencarb-free medium, none of the growth or physiological parameters were significantly different from controls, except that for a higher carbohydrate content in cells recovered from 3 mg L^{-1} thiobencarb (Table, 12).

Table (11): Effect of thiobencarb on *Anabaena variabilis* and its subsequent recovery. Means ± SD (n=3)

		Initial treatment				Recovery			
Time		Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}	Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}
2 days	Turbidity (A_{750})	0.18±0.01	0.09±0.00	0.8±0.00	0.07±0.00	0.08±0.01	0.08±0.00	0.15±0.00	0.15±0.01
4 days		0.34±0.01	0.13±0.02	0.11±0.00	0.11±0.00	0.31±0.04	0.31±0.03	0.43±0.02	0.42±0.02
6 days		0.41±0.02	0.14±0.01	0.13±0.00	0.13±0.01	0.52±0.08	0.49±0.04	0.64±0.03	0.16±0.03
8 days		0.56±0.02	0.22±0.01	0.17±0.01	0.16±0.01	0.77±0.08	0.77±0.04	0.90±0.03	0.87±0.04
10 days		0.63±0.02	0.39±0.02	0.21±0.01	0.21±0.01	0.92±0.10	0.90±0.04	1.02±0.04	0.98±0.05
2 days	Chlorophyll *a* (mg L^{-1})	0.50±0.01	0.41±0.01	0.41±0.03	0.35±0.02	0.40±0.04	0.32±0.01	0.51±0.02	0.56±0.02
4 days		0.98±0.05	0.66±0.02	0.67±0.02	0.66±0.02	0.62±0.11	0.58±0.11	0.76±0.02	0.77±0.02
6 days		0.76±0.06	0.66±0.04	0.63±0.02	0.66±0.05	0.86±0.11	0.80±0.06	1.01±0.02	1.08±0.04
8 days		1.21±0.04	1.08±0.04	1.12±0.06	1.13±0.05	1.43±0.11	1.47±0.17	1.59±0.11	1.61±0.05
10 days		2.30±0.22	1.36±0.17	1.43±0.05	1.53±0.15	1.87±0.14	1.75±0.17	2.09±0.18	1.95±0.06

Table (12): Growth and photosynthetic parameters of *Anabaena variabilis* on day 10 of thiobencarb treatment and recovery period. Means ± SD (n=3). Results of One-way ANOVA and Dunnett's one-sided comparison of treatments to controls indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

Thiobencarb $mg\ L^{-1}$	μ^{Chl} d^{-1}	Turbidity A_{750}	Chl *a* $mg\ L^{-1}$	DW $mg\ L^{-1}$	Chl *a* (mg g^{-1} DW)	Protein (mg g^{-1} DW)	Carbo. (mg g^{-1} DW)	F_v/F_m	Gross P_m (mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)	R_d (mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)
Control	0.17±0.02	0.63±0.02	2.30±0.22	247±2	9.3±0.8	102±9	79±11	0.48±0.01	307±53	-40±8
1.0	0.12±0.02**	0.39±0.02***	1.36±0.17***	243±6	5.6±0.6***	25±7***	80±3	0.48±0.02	296±84	-48±21
2.0	0.13±0.02**	0.21±0.01***	1.43±0.05***	149±6***	9.6±0.3	52±28**	137±18***	0.45±0.04	439±77*	-35±21
3.0	0.16±0.00	0.21±0.01***	1.53±0.15***	161±5***	9.5±0.7	50±12**	130±15**	0.39±0.04*	405±16	-26±17
One-way ANOVA	**	***	***	***	***	**	***	*	NS	NS
Recovery										
Control	0.19±0.04	0.92±0.10	1.87±0.14	360±32	5.2±0.2	145±22	102±36	0.41±0.02	440±49	-44±6
1.0	0.23±0.01	0.90±0.04	1.75±0.17	357±34	4.9±0.2	122±24	83±9	0.40±0.02	453±28	-38±12
2.0	0.17±0.01	1.02±0.04	2.09±0.18	388±17	5.4±0.2	176±25	133±18	0.44±0.02	603±271	-80±47
3.0	0.17±0.02	0.98±0.05	1.95±0.06	372±21	5.3±0.4	155±41	156±14*	0.43±0.02	621±139	-51±14
One-way ANOVA	*	NS	NS	NS	NS	NS	*	NS	NS	NS

(μ) Specific growth rate over days 2-6

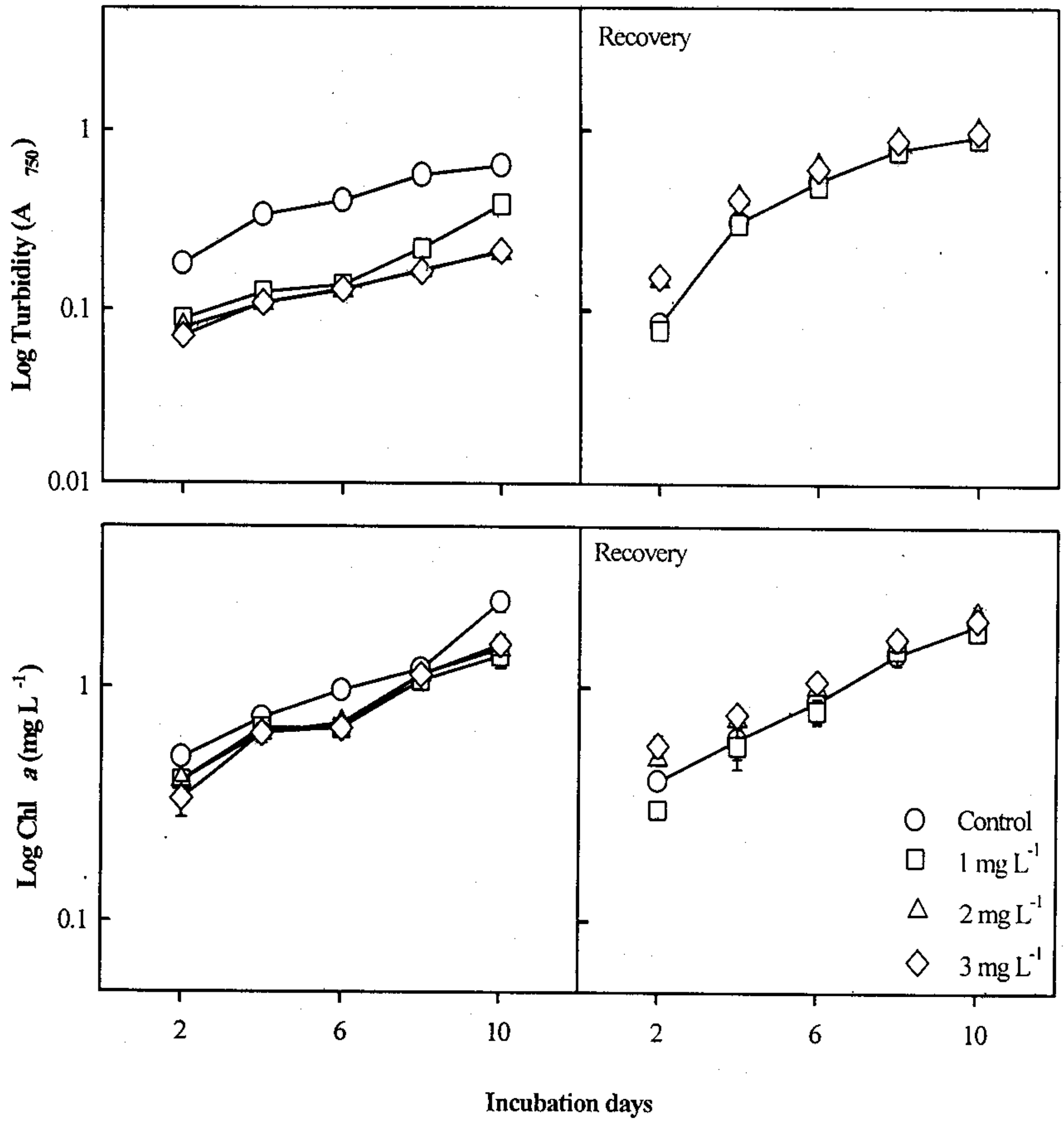

Fig. (5): Effect of thiobencarb on turbidity and chlorophyll a of *Anabaena variabilis* and its recovery. Means ± SD (n=3).

3- Effect of simazine on *Protosiphon* and its subsequent recovery

One-way ANOVA revealed a significant effect of simazine on *Protosiphon botryoides* for all variables except Chl *a* (mg g^{-1} DW) ratio and carbohydrate content (Table, 14). Specific growth rate (μ, days 2-8) significantly increased at low simazine treatment, but significantly decreased at the highest concentration. Turbidity, cell number, Chl *a* and DW yields significantly decreased at 0.4 and 0.8 mg L^{-1} simazine concentrations as presented in table (14) and illustrated in Fig. (6). Chl *a* (mg g^{-1} DW) increased significantly at 0.2 and 0.4 mg L^{-1} simazine. Dry weight normalized protein content increased significantly with increasing simazine concentration, whereas carbohydrate content was not significantly affected by simazine. Variable fluorescence to maximal fluorescence (F_v/F_m), which is an indicator of the photochemical efficiency of photosystem II significantly decreased with increasing simazine concentration (Table, 14). Gross photosynthesis normalized to chlorophyll *a* (P_m^{Chl}) significantly decreased at the highest simazine concentration, whereas dark respiration normalized to chlorophyll *a* (R_d^{Chl}) decreased significantly at 0.4 mg L^{-1} compared to the control. During the recovery period after subculture in simazine-free medium, none of the measured growth and photosynthetic parameters were significantly affected by prior simazine exposure (Table, 14).

Table (13): Effect of simazine on *Protosiphon botryoides* and its subsequent recovery. Means ± SD (n=3)

		Initial treatment				Recovery			
Time		Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}	Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}
2 days	Turbidity (A_{750})	0.11±0.00	0.09±0.01	0.06±0.01	0.05±0.00	0.05±0.01	0.05±0.01	0.05±0.01	0.04±0.00
4 days		0.16±0.02	0.10±0.00	0.06±0.01	0.05±0.01	0.11±0.01	0.10±0.01	0.12±0.00	0.10±0.01
6 days		0.20±0.00	0.16±0.01	0.08±0.01	0.06±0.01	0.19±0.00	0.16±0.01	0.18±0.01	0.16±0.01
8 days		0.25±0.01	0.21±0.00	0.10±0.01	0.06±0.01	0.26±0.01	0.21±0.03	0.25±0.01	0.24±0.02
12 days		0.36±0.01	0.32±0.01	0.15±0.01	0.08±0.01	0.36±0.01	0.29±0.04	0.35±0.01	0.34±0.01
16 days		0.46±0.01	0.42±0.03	0.18±0.01	0.08±0.01	0.42±0.02	0.37±0.05	0.38±0.03	0.40±0.02
2 days	Cell number x 10^4 (cell ml^{-1})	125±23	81±14	57±3	36±4	37±5	45±4	47±10	33±6
4 days		162±38	117±21	56±7	47±1	84±6	59±8	95±11	94±15
6 days		243±15	147±8	73±18	49±3	210±18	178±29	203±50	143±3
8 days		313±32	255±26	116±13	64±10	285±18	227±10	258±25	238±40
12 days		358±40	378±86	157±29	75±18	475±75	315±93	392±62	420±58
16 days		353±25	377±42	240±36	63±5	530±40	402±64	417±38	457±67
2 days	chlorophyll *a* (mg L^{-1})	0.92±0.07	0.70±0.01	0.47±0.07	0.49±0.05	0.36±0.08	0.33±0.01	0.41±0.09	0.22±0.04
4 days		1.11±0.06	0.76±0.02	0.41±0.04	0.41±0.07	0.62±0.04	0.55±0.09	0.63±0.05	0.63±0.09
6 days		1.49±0.05	1.18±0.24	0.55±0.02	0.44±0.02	1.12±0.04	0.91±0.04	1.07±0.06	0.96±0.11
8 days		1.64±0.05	1.67±0.08	0.70±0.04	0.51±0.06	1.50±0.11	1.33±0.07	1.53±0.06	1.32±0.06
12 days		2.72±0.15	2.87±0.96	1.22±0.25	0.62±0.04	1.74±0.30	1.49±0.28	1.91±0.19	1.77±0.02
16 days		2.89±0.26	3.18±0.26	1.66±0.31	0.63±0.13	1.89±0.19	1.68±0.29	1.82±0.06	1.85±0.15

Table (14): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of simazine treatment and recovery period. Means ± SD (n=3). Results of One-way ANOVA and Dunnett's one-sided comparison of treatments to controls indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

Simazine mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* (mg g^{-1} DW)	Protein (mg g^{-1} DW)	Carbo. (mg g^{-1} DW)	F_v/F_m	Gross P_m (Mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)	R_d (Mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)
Control	0.10±0.01	0.46±0.01	373±35	2.89±0.26	401±36	7.3±1.2	89±13	143±14	0.77±0.01	135±17	-29±4
0.2	0.15±0.01**	0.42±0.03	417±63	3.35±0.55	315±6	10.7±2.0*	96±7	160±15	0.73±0.00***	135±12	-20±2
0.4	0.09±0.01	0.18±0.01***	240±36**	1.66±0.31**	149±8***	11.1±2.1*	157±9***	169±68	0.68±0.01***	121±15	-11±8**
0.8	0.04±0.01***	0.08±0.01***	79±11***	0.66±0.08***	83±5***	8.0±1.4	251±16***	110±6	0.57±0.01***	97±14*	-33±4
One-way ANOVA	***	***	***	***	***	NS	***	NS	***	*	**
Recovery											
Control	0.25±0.04	0.42±0.02	530±40	1.89±0.19	301±6	6.3±0.5	112±6	171±8	0.77±0.02	210±43	-35±11
0.2	0.23±0.01	0.37±0.05	420±51*	1.68±0.29	307±23	5.5±1.0	119±9	190±23	0.78±0.00	160±6	-35±6
0.4	0.22±0.03	0.38±0.03	428±47*	1.92±0.17	299±6	6.4±0.4	109±2	192±36	0.79±0.02	143±9*	-31±9
0.8	0.29±0.02	0.40±0.02	463±55	1.87±0.13	319±21	5.9±0.4	107±7	175±7	0.79±0.01	186±27	-20±10
One-way ANOVA	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

(μ) Specific growth rate over days 2-8

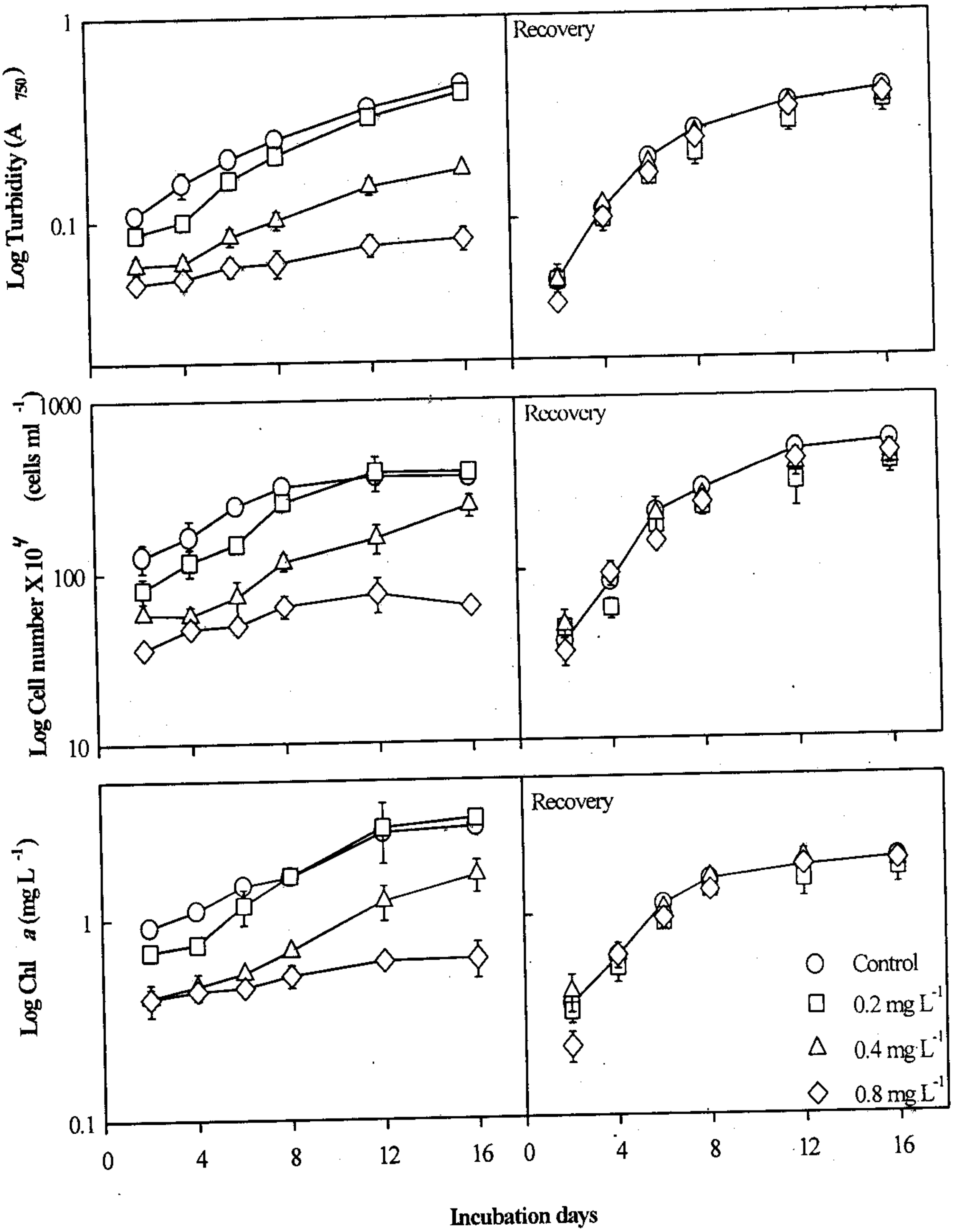

Fig. (6): Effect of simazine on turbidity, cell number and chlorophyll *a* of *Protosiphon botryoides* and its recovery. Means ± SD (n=3).

4- Effect of simazine on *Anabaena* and its subsequent recovery

Growth and physiological measurements of *Anabaena variabilis* incubated for 10 days in standard BG-11 medium containing different simazine concentrations, using One-way ANOVA revealed a significant effect of simazine on all variables except specific growth rate (μ) and variable fluorescence to maximal fluorescence ratio (F_v/F_m) as presented in table (16). Specific growth rate (μ, days 2-6) significantly decreased at the highest simazine treatments. Turbidity, Chl *a* and DW yields, and Chl *a* (mg g^{-1} DW) significantly decreased with increasing simazine concentration as presented in table (16) and illustrated in Fig. (7). Dry weight normalized protein increased significantly at 0.4 and 0.8 mg L^{-1} simazine, whereas carbohydrate content significantly decreased at the highest concentration. F_v/F_m ratio was unaffected by simazine. Gross photosynthesis normalized to chlorophyll *a* (P_m^{Chl}) and dark respiration normalized to chlorophyll *a* (R_d^{Chl}) were increased significantly with increasing in simazine dose as compared to control. After 10 days of subculture of *Anabaena* cells in simazine-free medium, some variables (μ, turbidity and P_m^{Chl}) were identified by Dunnett's test as significantly higher in cultures previously exposed to simazine, although the ANOVA indicated no significant treatment effect (Table, 16).

Table (15): Effect of simazine on *Anabaena variabilis* and its subsequent recovery. Means ± SD (n=3)

		Initial treatment				Recovery			
Time		Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}	Control	1 mgL^{-1}	2 mgL^{-1}	3 mgL^{-1}
2 days	Turbidity (A_{750})	0.14±0.01	0.11±0.00	0.08±0.01	0.06±0.00	0.09±0.01	0.11±0.02	0.10±0.01	0.12±0.00
4 days		0.19±0.03	0.14±0.00	0.12±0.01	0.07±0.00	0.24±0.03	0.27±0.01	0.28±0.03	0.31±0.02
6 days		0.45±0.08	0.27±0.01	0.20±0.01	0.09±0.00	0.44±0.04	0.49±0.02	0.56±0.00	0.58±0.03
8 days		0.61±0.05	0.37±0.01	0.28±0.01	0.11±0.00	0.67±0.04	0.73±0.02	0.80±0.01	0.79±0.04
10 days		0.82±0.06	0.52±0.01	0.31±0.01	0.13±0.01	0.89±0.07	0.97±0.02	1.00±0.06	1.00±0.01
2 days	chlorophyll *a* ($mg\ L^{-1}$)	0.54±0.10	0.39±0.03	0.30±0.03	0.19±0.01	0.45±0.11	0.37±0.08	0.42±0.06	0.42±0.02
4 days		0.66±0.13	0.39±0.02	0.35±0.05	0.17±0.02	0.76±0.12	0.79±0.04	0.93±0.13	0.98±0.10
6 days		1.07±0.10	0.65±0.02	0.52±0.02	0.23±0.02	1.17±0.11	1.28±0.02	1.49±0.09	1.53±0.16
8 days		1.81±0.15	0.98±0.09	0.70±0.04	0.31±0.02	1.18±0.15	1.39±0.09	1.71±0.15	1.56±0.06
10 days		2.23±0.11	1.25±0.00	0.88±0.05	0.42±0.02	1.85±0.16	1.92±0.07	2.01±0.18	1.89±0.11

Table (16): Growth and photosynthetic parameters of *Anabaena variabilis* on day 10 of simazine treatment and recovery periods. Means ± SD (n=3). Results of One-way ANOVA and Dunnett's one-sided comparison of treatments to controls indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

Simazine mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* (mg g^{-1} DW)	Protein (mg g^{-1} DW)	Carbo. (mg g^{-1} DW)	F_v/F_m	Gross P_m (mol O_2·g^{-1}chl·h^{-1})	R_d (mol O_2·g^{-1}chl·h^{-1})
Control	0.18±0.06	0.82±0.06	2.23±0.11	283±36	7.9±0.6	167±13	140±26	0.38±0.02	233±28	-19±8
0.2	0.14±0.02	0.52±0.01***	1.25±0.00***	195±13***	6.4±0.4**	198±13	133±6	0.41±0.02	407±42***	-54±10**
0.4	0.14±0.01	0.31±0.01***	0.88±0.05***	153±5***	5.8±0.4***	238±13**	111±14	0.42±0.05	533±29***	-39±10*
0.8	0.08±0.02*	0.13±0.01***	0.42±0.02***	91±6***	4.7±0.4***	337±29***	100±2*	0.39±0.03	380±33***	-49±10**
One-way ANOVA	NS	***	***	***	***	***	*	NS	***	**
Recovery										
Control	0.23±0.06	0.89±0.07	1.85±0.16	344±14	5.4±0.3	139±10	115±12	0.42±0.02	613±20	-55±30
0.2	0.32±0.06*	0.97±0.02	1.92±0.07	355±12	5.4±0.1	132±2	119±25	0.40±0.02	624±35	-32±19
0.4	0.32±0.03*	1.00±0.06*	2.01±0.18	335±18	6.0±0.5	145±11	133±19	0.41±0.02	715±88*	-36±33
0.8	0.31±0.01	1.00±0.01*	1.89±0.11	337±14	5.6±0.5	145±7	125±11	0.39±0.02	772±35**	-19±5
One-way ANOVA	NS	NS	NS	NS	NS	NS	NS	NS	*	NS

(μ) Specific growth rate over days 2-6

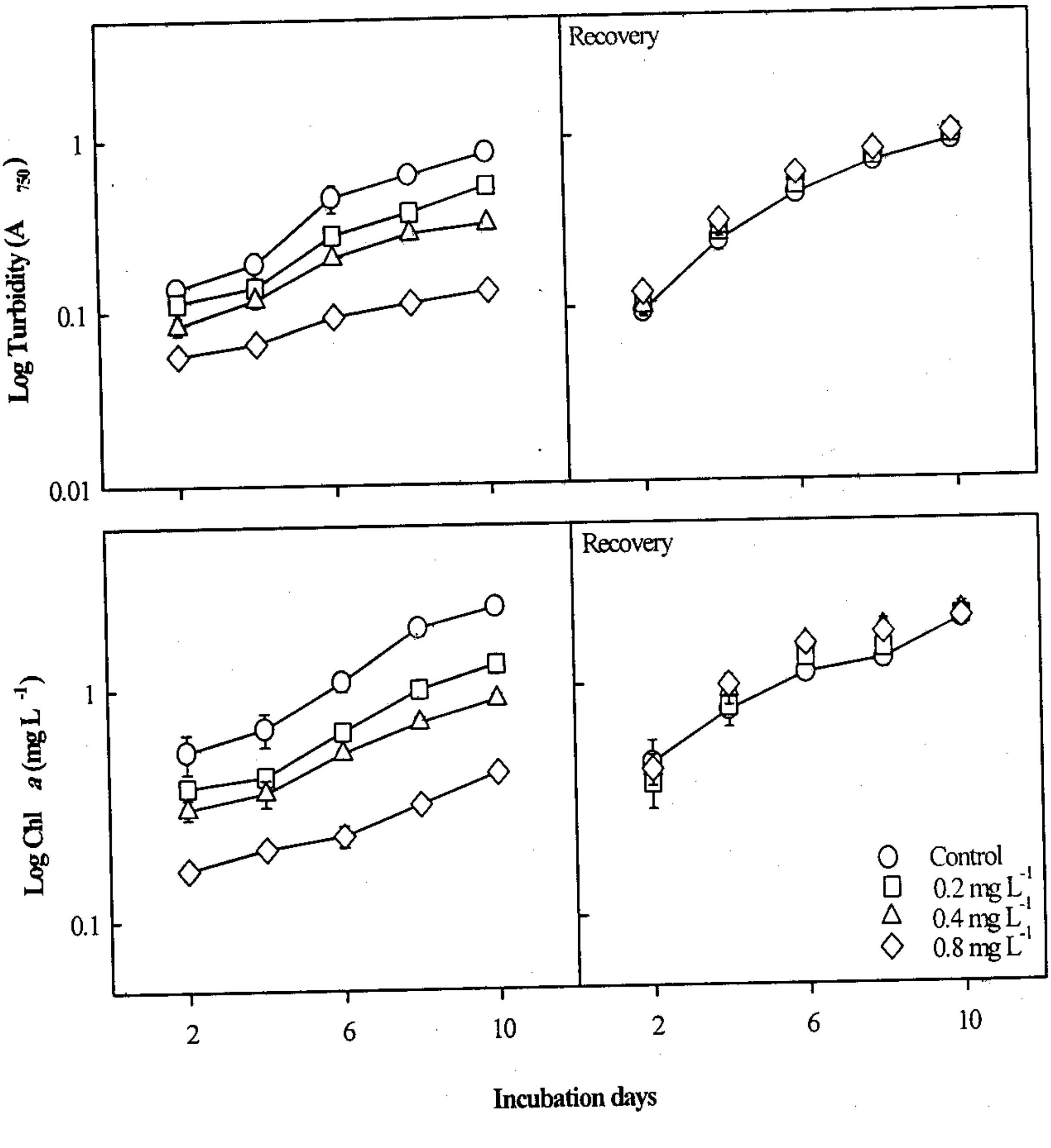

Fig. (7): Effect of simazine on turbidity and chlorophyll *a* of *Anabaena variabilis* and its recovery. Means ± SD (n=3).

5- Effect of pendimethalin on *Protosiphon* and its subsequent recovery

Growth and physiological measurements of *Protosiphon botryoides* incubated for 16 days in standard BBM containing different pendimethalin concentrations, using One-way ANOVA revealed a significant effect of pendimethalin on *P. botryoides* for all variables except gross photosynthesis normalized to chlorophyll *a* (P_m^{Chl}) and dark respiration normalized to (R_d^{Chl}). Specific growth rate (μ, days 2-8), turbidity, cell number, Chl *a* and DW yields significantly decreased with increasing pendimethalin concentration as presented in table (18) and illustrated in Fig. (8). Chl *a* (mg g^{-1} DW) increased at 0.25 mg L^{-1} pendimethalin, but decreased at the highest concentration. Dry weight normalized protein and carbohydrate content significantly increased with increase in pendimethalin concentration. Variable fluorescence to maximum fluorescence ratio (F_v/F_m) ratio was slightly but significantly reduced at all concentrations of pendimethalin. Gross P_m^{Chl} significantly decreased at the highest pendimethalin concentration, whereas R_d^{Chl} was unaffected by pendimethalin. In contrast to thiobencarb and simazine, *P. botryoides* did not fully recover within 16 days after subculture in pendimethalin-free medium as shown Table (18) and Fig. (8). Chl *a* (mg g^{-1} DW), protein, carbohydrate and R_d^{Chl} were not significantly different from controls. However, μ and gross P_m^{Chl} were actually higher than controls giving highly significant values, whereas other variables were still slightly lower.

Table (18): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of pendimethalin treatment and recovery period. Means ± SD (n=3). Results of One-way ANOVA and Dunnett's one-sided comparison of treatments to controls indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

Pendimethalin mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times 10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* (mg g^{-1} DW)	Protein (mg g^{-1} DW)	Carbo. (mg g^{-1} DW)	F_v/F_m	Gross P_m (mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)	R_d (mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$)
Control	0.16±0.03	0.36±0.02	288±25	2.10±0.11	240±7	8.8±0.3	111±8	136±8	0.72±0.01	188±8	-54±16
0.25	0.13±0.01	0.16±0.03***	100±10***	1.18±0.14***	115±15***	10.3±0.4*	195±24*	167±21	0.65±0.03**	169±28	-33±8
0.5	0.08±0.03**	0.06±0.01***	22±7***	0.73±0.24***	84±21***	8.6±0.9	264±68**	178±38	0.68±0.01*	178±25	-63±53
1.0	0.07±0.01**	0.04±0.00***	4±1***	0.37±0.05***	56±7***	6.5±0.6**	382±42***	206±22**	0.65±0.01**	115±49*	-78±88
One-way ANOVA	**	***	***	***	***	***	***	*	**	NS	NS
Recovery											
Control	0.24±0.02	0.45±0.05	453±28	2.71±0.26	417±15	6.5±0.4	77±3	161±8	0.79±0.00	169±17	-31±4
0.25	0.25±0.04	0.41±0.05	335±50**	2.38±0.19	357±15*	6.7±0.8	90±2	168±34	0.81±0.02	305±39***	-40±16
0.5	0.35±0.02**	0.38±0.02	388±33	2.26±0.22*	327±29**	6.9±0.2	93±12	158±19	0.76±0.00*	288±15***	-39±9
1.0	0.40±0.05***	0.26±0.00***	217±29***	1.57±0.11***	290±36***	5.5±1.1	97±18	139±43	0.74±0.02**	296±2***	-53±20
One-way ANOVA	***	***	***	***	**	NS	NS	NS	***	***	NS

(μ) Specific growth rate over days 2-8

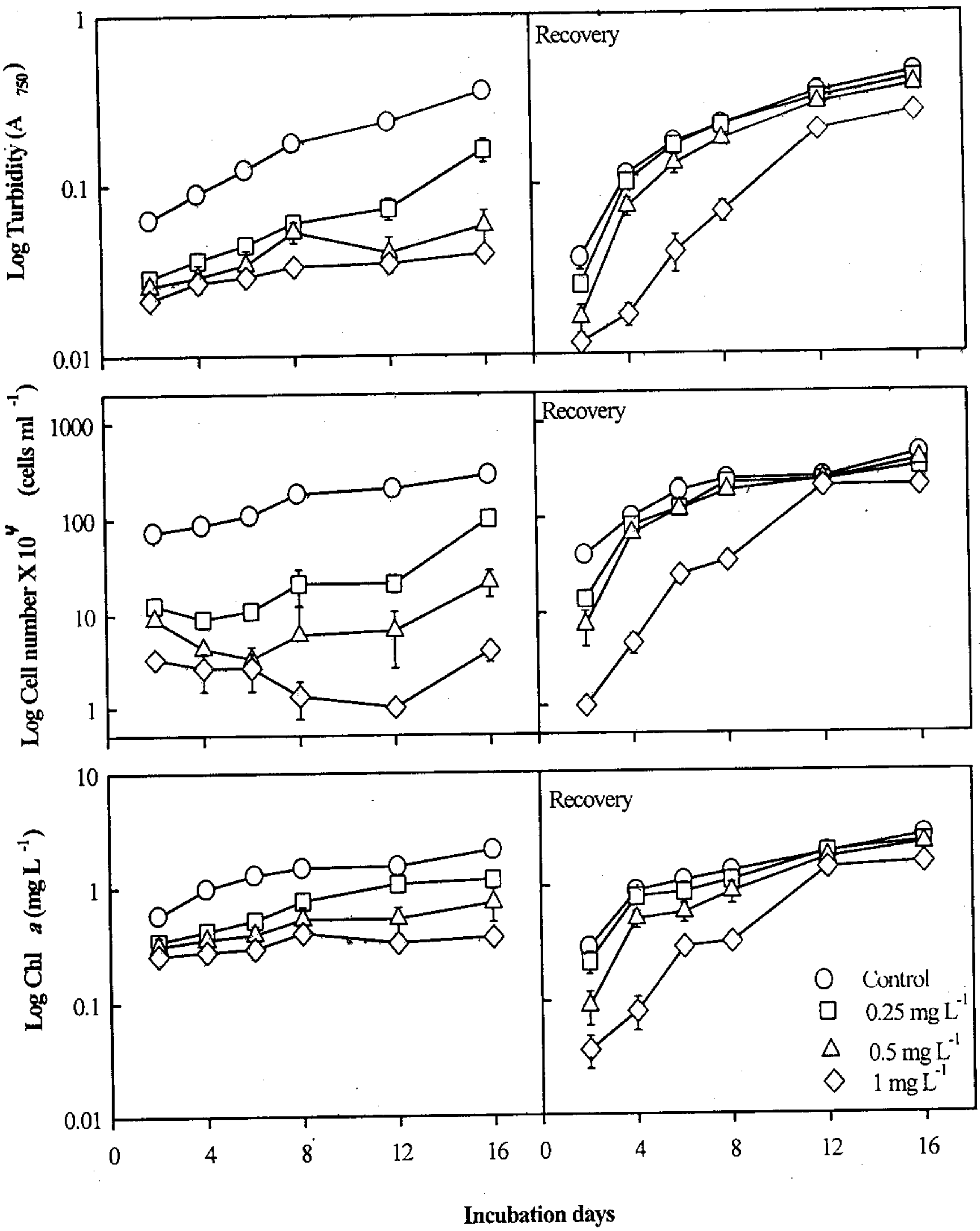

Fig. (8): Effect of pendimethalin on turbidity, cell number and chlorophyll *a* of *Protosiphon botryoides* and its recovery. Means ± SD (n=3).

II-Nitrate effect on herbicide toxicity

1-Nitrate effect on thiobencarb toxicity to *Protosiphon*

Growth and photosynthetic parameters were measured to study the effect of nitrate concentration on the sensitivity of *Protosiphon botryoides* to thiobencarb. With varying nitrate concentration at normal BBM media where phosphate concentration was (1.7 mM), Two-way ANOVA revealed highly significant effect of thiobencarb on all measured variables, whereas the effect on specific growth rate was significant. Effect of nitrate concentration was significant on turbidity, cell number, Chl *a* and DW yields, Chl *a* (mg g^{-1} DW) and gross P_m^{Chl} (Table, 19). Nitrate and thiobencarb interaction significantly affected turbidity, cells number and Chl *a* yield, Chl *a* (mg g^{-1} DW), and gross P_m^{Chl}. Within each nitrate level, turbidity, cell number, Chl *a* and DW yields, and Chl *a* (mg g^{-1} DW) ratio significantly decreased with increasing thiobencarb concentration (Table, 19), whereas specific growth rate (μ) was unaffected when compared to control values. Comparing the effect of nitrate level within each thiobencarb level (Figs. 9-11), turbidity, cell number and Chl *a* yields switched from a negative nitrate effect in the absence of thiobencarb to a positive nitrate effect at 2 and 3 mg L^{-1} thiobencarb. In contrast, DW yield was positively related to nitrate at all thiobencarb concentrations (Fig. 10), and P_m^{Chl} switched from a positive nitrate effect in controls to a negative effect in the presence of thiobencarb (Fig. 11). The effect of thiobencarb on gross P_m^{Chl} was fluctuating, because of the strong interaction with nitrate and the absence of an obvious trend with increasing thiobencarb. In contrast, R_d^{Chl} exhibited a clear increase in the presence of thiobencarb, and at 0, 1 and 2 mg L^{-1} thiobencarb, R_d^{Chl} decreased with increasing nitrate at thiobencarb higher doses (Fig. 11).

Table (19): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of nitrate and thiobencarb treatment period. Means ± SD (n=3). Results of Two-way ANOVA and Dunnett's one-sided comparison of treatments to controls at the same nitrate level indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

NO_3 mM	Thiobencarb mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* mg g^{-1} DW	F_v/F_m	Gross P_m mol $O_2 \cdot g^{-1}$ chl$\cdot h^{-1}$	R_d mol $O_2 \cdot g^{-1}$ chl$\cdot h^{-1}$
1.0	Control	0.12±0.01	0.65±0.09	570±61	2.87±0.14	517±57	5.6±0.8	0.77±0.02	143±48	-27±27
	1.0	0.13±0.02	0.66±0.02	778±133*	3.00±0.17	420±36*	7.2±0.2*	0.68±0.01***	160±12	-39±2
	2.0	0.13±0.02	0.34±0.01***	348±45**	1.84±0.04***	273±25***	6.8±0.6*	0.69±0.02***	242±39**	-46±26
	3.0	0.10±0.02	0.19±0.02***	238±29***	1.17±0.19***	190±36***	6.2±0.5	0.71±0.01***	298±23***	-90±18**
3.0	Control	0.12±0.01	0.55±0.03	420±68	3.15±0.17	663±25	4.8±0.2	0.75±0.01	223±31	-38±7
	1.0	0.14±0.01	0.56±0.02	483±78	3.18±0.28	623±55	5.1±0.6	0.70±0.02	145±4*	-46±11
	2.0	0.08±0.02*	0.36±0.04***	361±63	2.06±0.25***	357±15***	5.8±0.5	0.70±0.01*	154±66	-60±5
	3.0	0.10±0.01	0.27±0.05***	303±70	1.57±0.13***	260±66***	6.3±1.3*	0.68±0.05*	298±13*	-93±19***
9.0	Control	0.12±0.01	0.44±0.02	343±79	2.59±0.23	627±95	4.2±0.8	0.76±0.01	273±6	-44±14
	1.0	0.11±0.01	0.44±0.01	347±64	2.65±0.27	647±6	4.1±0.4	0.70±0.02*	65±8***	-51±11
	2.0	0.11±0.01	0.35±0.03***	385±70	2.22±0.26	370±62***	6.0±0.4**	0.74±0.00	82±26***	-61±6
	3.0	0.11±0.02	0.27±0.02***	333±101	1.64±0.32**	250±46***	6.6±0.2***	0.72±0.02	187±24***	-71±7*
Two-way ANOVA										
Nitrate		NS	***	***	*	***	***	NS	***	NS
Thiobencarb		**	***	***	***	***	***	***	***	***
NO_3+Thiobencarb		NS	***	***	*	NS	**	NS	***	NS

(μ) Specific growth rate over days 2-8

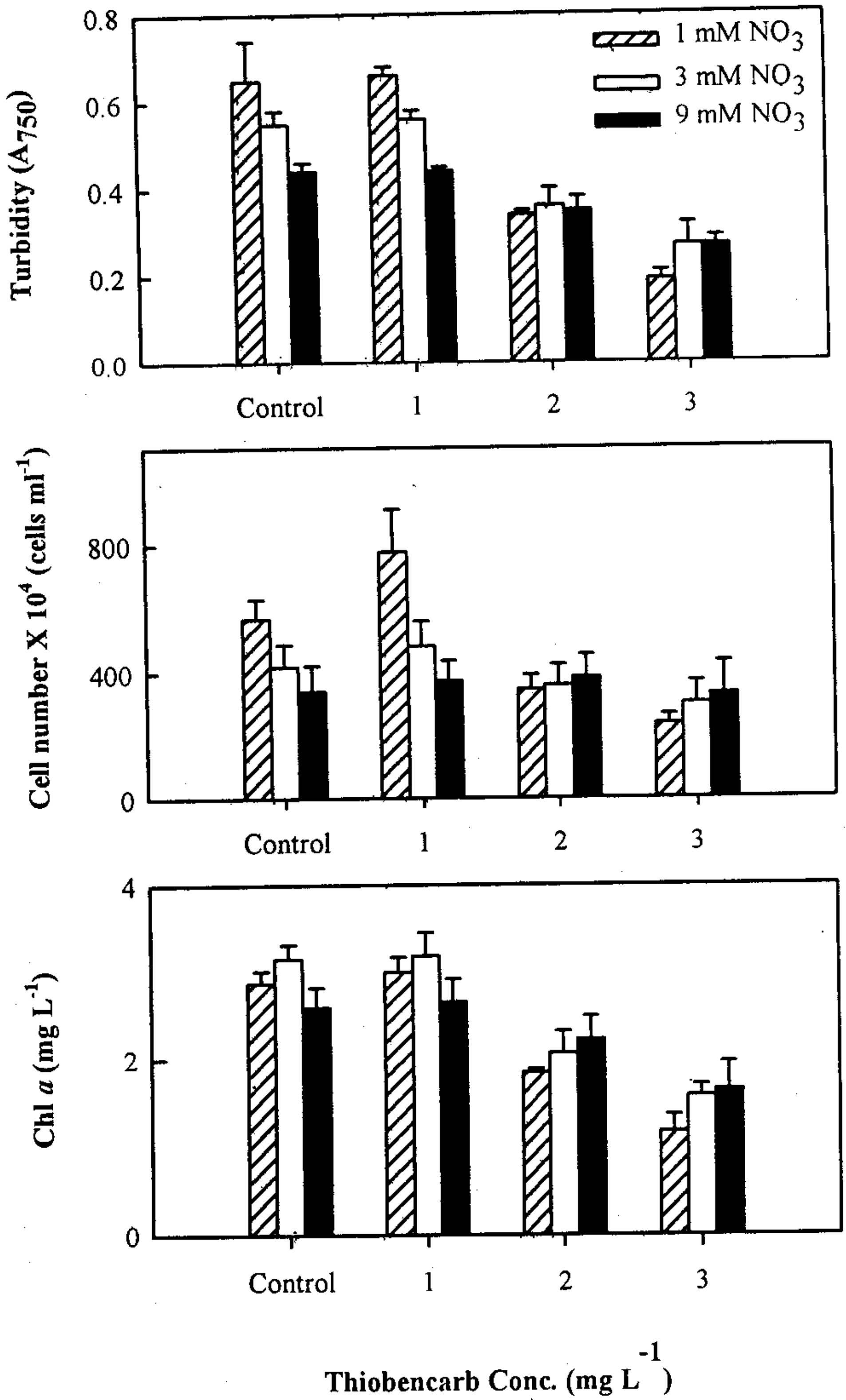

Fig. (9): Effect of nitrate interaction with thiobencarb on turbidity, cell number and Chl *a* content of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

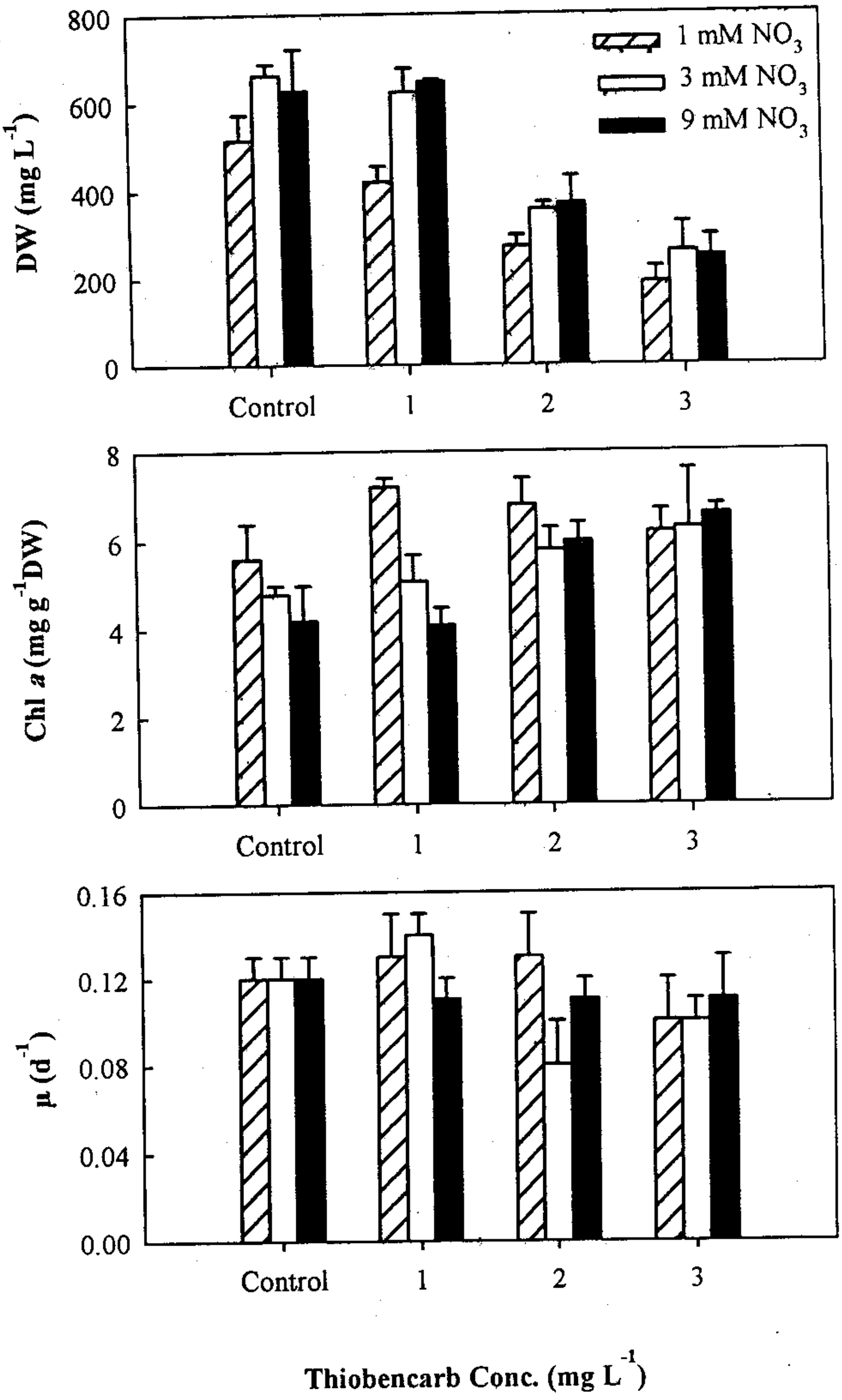

Fig. (10): Effect of nitrate interaction with thiobencarb on DW, Chl *a* (mg g^{-1}DW) and μ of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

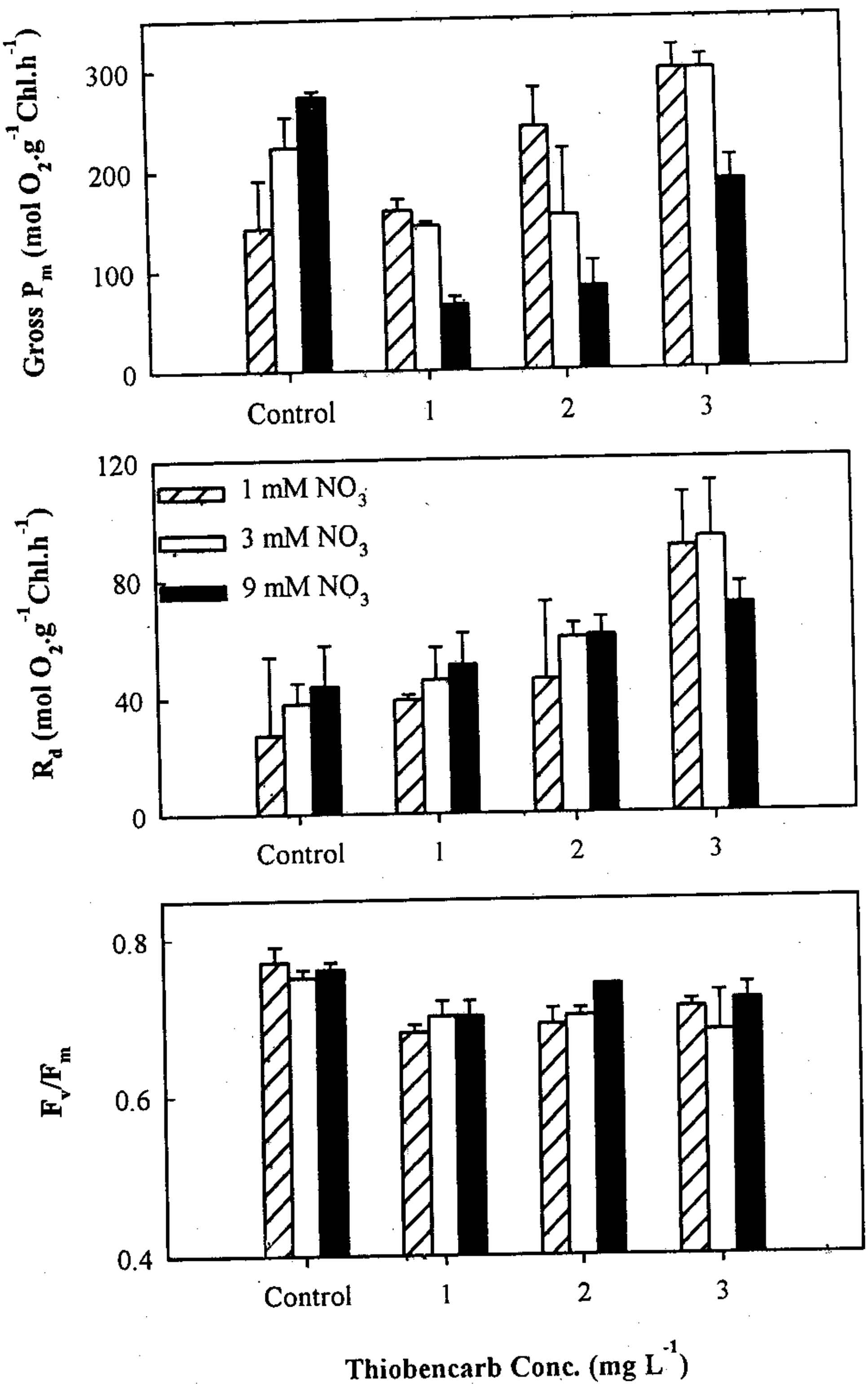

Fig. (11): Effect of nitrate interaction with thiobencarb on gross P_m, R_d and F_v/F_m of *Protosiphon botryoidcs* after 16 days of incubation. Means ± SD (n=3)

2-Nitrate effect on pendimethalin toxicity to *Protosiphon*

Growth and photosynthetic parameters were measured to study the effect of nitrate concentration on the sensitivity of *Protosiphon botryoides* to pendimethalin. With varying nitrate concentration BBM media where phosphate concentration was (1.7 mM), Two-way ANOVA revealed a significant primary effect of pendimethalin on all measured variables, and a significant primary effect of nitrate concentration and nitrate with pendimethalin interaction on turbidity, cells number, Chl *a* and DW yields, and gross P_m^{Chl} (Table, 20). Within each nitrate level specific growth rate (μ, days 2-8) and turbidity, cell number, Chl *a* and DW yields significantly decreased with increasing pendimethalin concentration (Table, 20). Within each pendimethalin level, turbidity, cell number, Chl *a* and DW yields values tended to decrease at 15 mM nitrate as compared with control nitrate level (3mM), and at 0.25 mg L^{-1} pendimethalin, biomass yield also decreased at 0.6 mM nitrate relative to normal BBM (3 mM nitrate; Fig. 12). Contrary to the initial experiment (Table, 18), gross P_m^{Chl} and dark respiration rate significantly increased at 1 mg L^{-1} pendimethalin as compared to its control (Table, 20). However, gross P_m^{Chl} did not increase following a 16 days incubation period in the initial time-dose experiment (Table, 18).

Table (20): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of nitrate and pendimethalin treatment period. Means ± SD (n=3). Results of Two-way ANOVA and Dunnett's one-sided comparison of treatments to controls at the same nitrate level indicate * P < 0.05; ** P < 0.01; *** P < 0.001; NS, not significant.

NO_3 mM	Pendimethalin mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* mg g^{-1} DW	F_v/F_m	Gross P_m mol $O_2 \cdot g^{-1}chl \cdot h^{-1}$	R_d mol $O_2 \cdot g^{-1}chl \cdot h^{-1}$
0.6	Control	0.17±0.02	0.35±0.00	252±37	1.50±0.22	291±6	5.2±0.7	0.73±0.06	218±7	-27±4
	0.25	0.08±0.02***	0.16±0.01***	90±5***	0.97±0.06***	138±34***	7.3±1.7*	0.77±0.02	221±35	-48±30
	0.5	0.10±0.01**	0.21±0.01***	185±28*	1.17±0.07*	180±12***	6.5±0.5	0.77±0.01	113±24	-31±16
	1.0	0.09±0.01***	0.08±0.01***	24±14***	0.46±0.06***	63±8***	7.4±0.7*	0.75±0.02	750±178***	-68±26
3.0	Control	0.17±0.06	0.31±0.03	183±21	1.88±0.19	341±22	5.5±0.3	0.69±0.07	175±22	-24±6
	0.25	0.12±0.01	0.30±0.06	273±87	1.71±0.41	199±32***	8.6±1.9*	0.78±0.00*	211±7	-34±6
	0.5	0.13±0.06	0.15±0.04**	225±67	1.01±0.09**	177±21***	5.8±1.0	0.75±0.01	124±11	-33±3
	1.0	0.07±0.03*	0.08±0.01***	18±6**	0.48±0.09***	70±10***	6.8±0.4	0.74±0.00	591±168***	-71±27**
15	Control	0.14±0.01	0.24±0.01	160±65	1.42±0.15	216±56	6.9±1.8	0.76±0.08	165±40	-22±12
	0.25	0.07±0.01**	0.12±0.01***	65±26*	0.76±0.09***	107±10**	7.1±0.6	0.80±0.01	157±17	-13±8
	0.5	0.10±0.00	0.09±0.01***	63±24*	0.60±0.02***	96±12**	6.3±0.6	0.78±0.02	192±30	-53±17*
	1.0	0.11±0.03	0.06±0.01***	13±0**	0.42±0.02***	69±8***	6.2±0.4	0.77±0.00	294±39**	-36±13
Two-way ANOVA										
Nitrate		NS	***	***	***	***	NS	NS	**	NS
Pendimethalin		***	***	***	***	***	**	*	***	**
NO_3+Pendimethalin		NS	***	***	***	**	NS	NS	***	NS

(μ) Specific growth rate over days 2-8

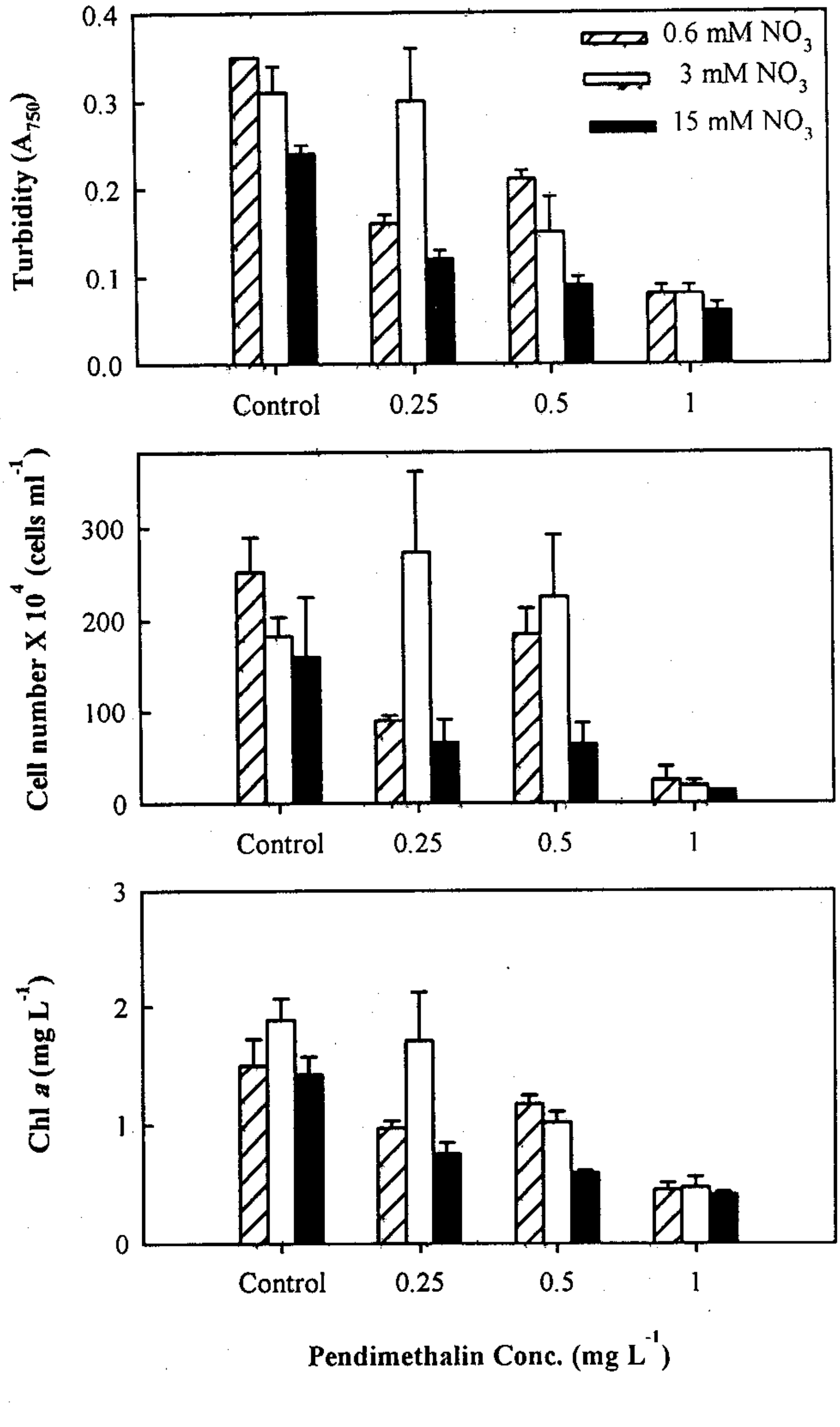

Fig. (12): Effect of nitrate interaction with pendimethalin on turbidity, cell number and Chl *a* content of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

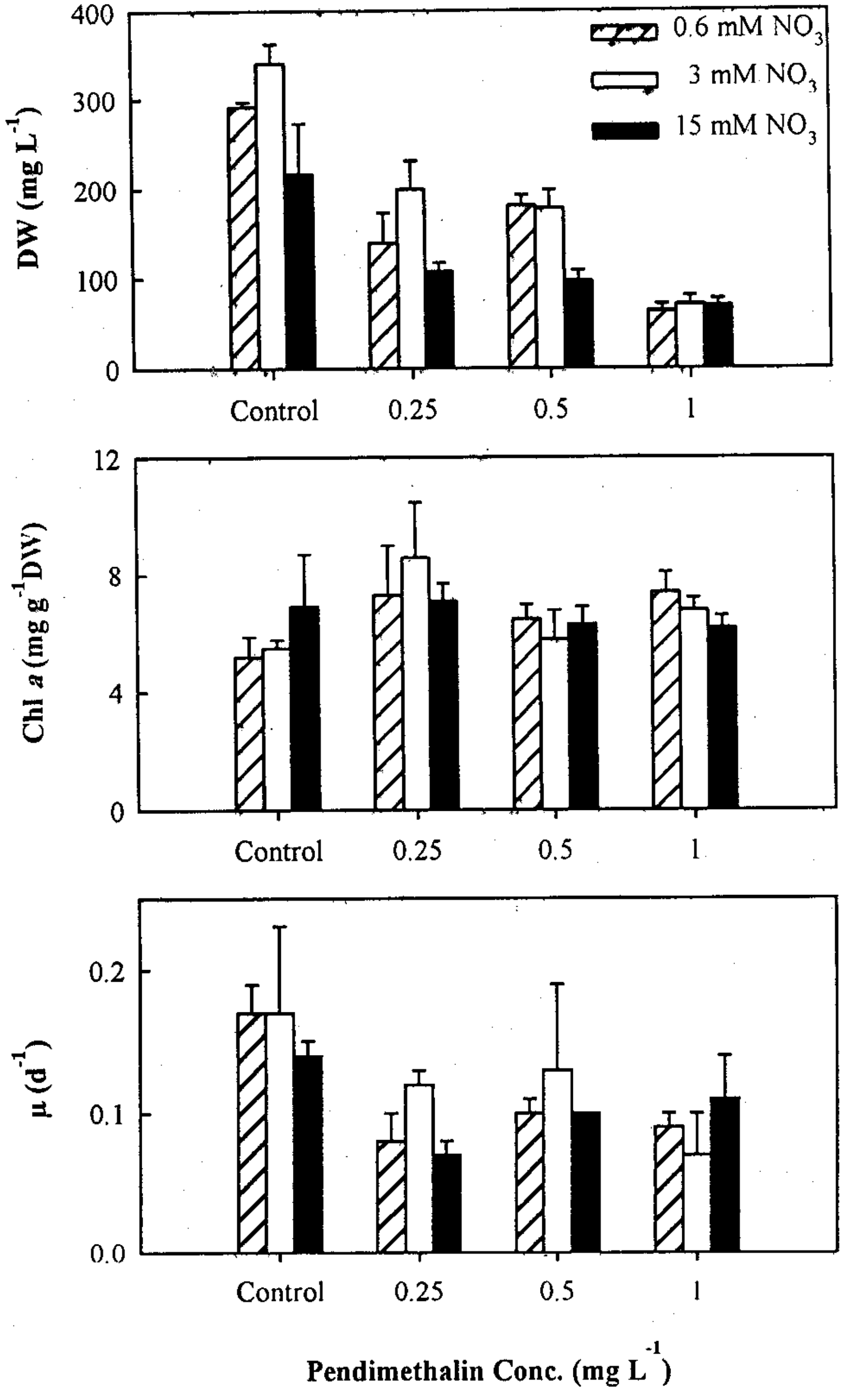

Fig. (13): Effect of nitrate interaction with pendimethalin on DW, Chl *a* (mg g^{-1}DW) and μ of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

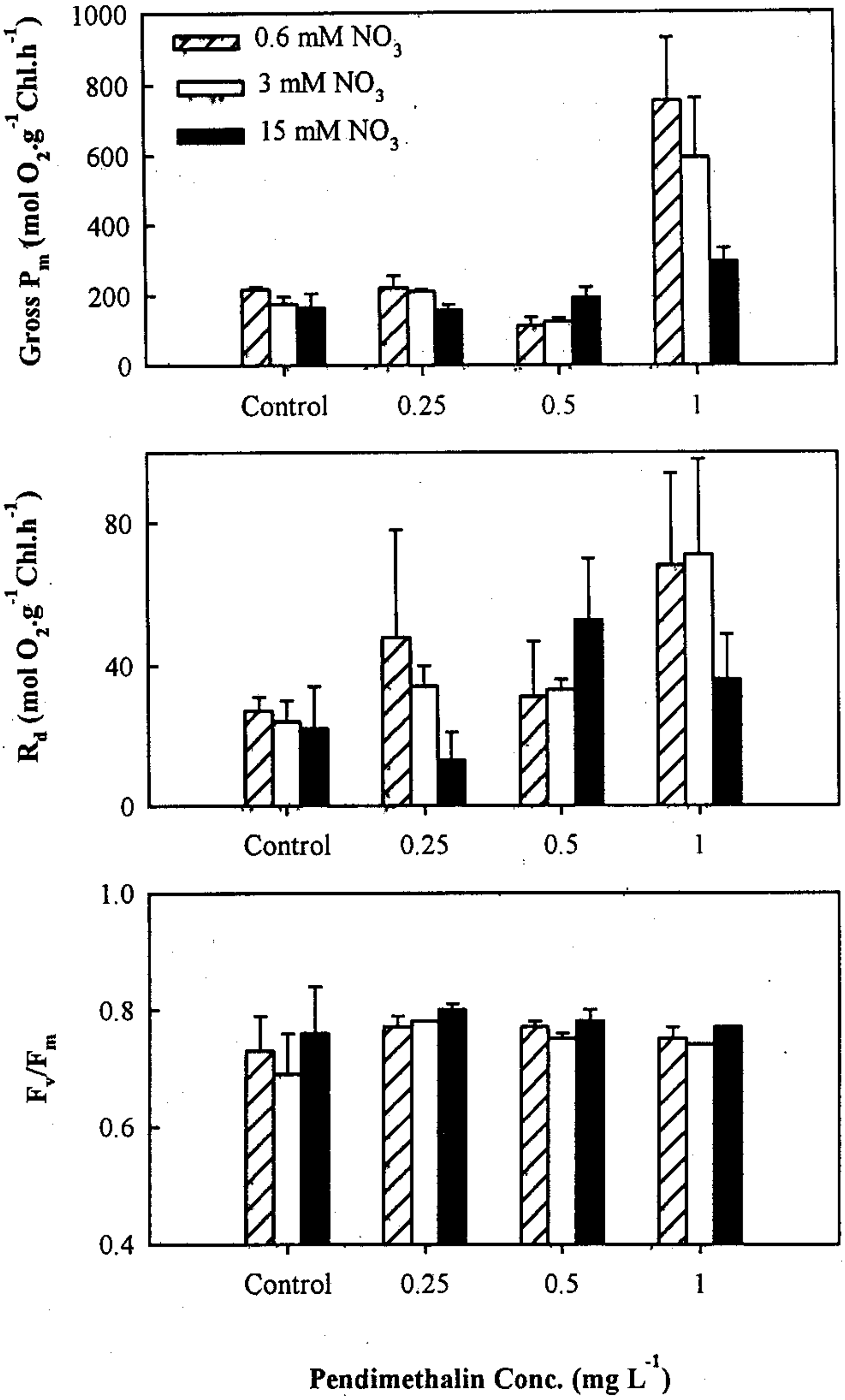

Fig. (14): Effect of nitrate interaction with pendimethalin on gross P_m, R_d and F_v/F_m of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

III-Phosphate effect on herbicide toxicity

1-Phosphate effect on thiobencarb toxicity to *Protosiphon*

To test the effect of phosphate concentration on the sensitivity of *Protosiphon botryoides* to thiobencarb, different phosphate concentrations were added to BBM media with nitrate concentration (3 mM) were conducted. Two-way ANOVA revealed that both phosphate and thiobencarb significantly affected specific growth rate (μ, days 2-8), turbidity, cell number, Chl *a* and DW yields, F_v/F_m and gross P_m^{Chl}. Thiobencarb also significantly affected R_d^{Chl} whereas phosphate significantly affected Chl *a* (mg g^{-1} DW) (Table, 21). Phosphate and thiobencarb interaction was significant only for of F_v/F_m ratio and gross P_m^{Chl}. Comparing thiobencarb treatments within different phosphate levels, specific growth rate (μ), turbidity, cells number, Chl *a* and DW yields decreased significantly at 2 and 3 mg L^{-1} thiobencarb (Table, 21). Thiobencarb effect on μ and biomass yield was low but significant, particularly at 5 mM phosphate. In the absence of thiobencarb, high phosphate level (5 mM) reduced DW yield Fig. (16). However, turbidity, cell number and Chl *a* yields in controls were inversely related to phosphorus concentrations (Fig. 15). Phosphate at 5 mM level tended to increase the inhibitory effect of thiobencarb on biomass yield especially at higher concentration Fig. (15) and specific growth rate (μ) Fig. (16). In the absence of thiobencarb, gross P_m^{Chl} and R_d^{Chl} were positively related to nitrate (Fig. 11) and negatively related to phosphate (Fig 17), this provides further evidence of a detrimental effect of N:P<1 on *P. botryoides*. Chl *a* (mg g^{-1} DW) significantly increased due to increase in thiobencarb concentration at 0.6 and 1.7mM phosphate (Table, 21). F_v/F_m variations were not obviously related to thiobencarb. Gross P_m^{Chl} significantly increased at 3 mg L^{-1} thiobencarb at 1.7 & 5 mM phosphate levels, while R_d^{Chl} significantly increased at 3 mg L^{-1} thiobencarb at all phosphate levels.

Table (21): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of phosphate and thiobencarb treatment period. Means ± SD (n=3). Results of Two-way ANOVA and Dunnett's one-sided comparison of treatments to controls at the same phosphate level indicate * $P < 0.05$; ** $P < 0.01$; *** $P < 0.001$; NS, not significant.

PO_4 mM	Thiobencarb mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times 10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* mg g^{-1} DW	F_v/F_m	Gross P_m mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$	R_d mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$
0.6	Control	0.13±0.02	0.55±0.02	523±30	2.89±0.04	630±60	4.6±0.4	0.71±0.01	287±35	-48±7
	1.0	0.13±0.01	0.51±0.05	592±113	3.06±0.11	550±85	5.6±0.7	0.66±0.01***	246±23	-30±2*
	2.0	0.10±0.02*	0.31±0.04***	547±45	2.23±0.17***	267±23***	8.4±0.3***	0.71±0.01	199±20*	-60±6
	3.0	0.09±0.01*	0.17±0.00***	302±27**	1.15±0.02***	140±17***	8.3±0.9***	0.73±0.01	240±48	-96±14***
1.7	Control	0.12±0.01	0.55±0.03	420±68	3.15±0.17	663±25	4.8±0.2	0.75±0.01	223±31	-38±7
	1.0	0.14±0.01	0.56±0.02	483±78	3.18±0.28	623±55	5.1±0.6	0.70±0.02	145±4*	-46±11
	2.0	0.08±0.02*	0.36±0.04***	362±63	2.06±0.25***	357±15***	5.8±0.5	0.70±0.01*	154±66	-59±5
	3.0	0.10±0.01	0.27±0.05***	303±70	1.57±0.13***	260±66***	6.3±1.3*	0.68±0.05*	298±13*	-93±19***
5.0	Control	0.13±0.03	0.37±0.11	337±75	1.61±0.65	517±106	5.3±2.4	0.76±0.01	185±24	-41±3
	1.0	0.11±0.01	0.32±0.04	287±37	2.44±0.31	447±156	6.1±2.6	0.72±0.00**	199±17	-31±2
	2.0	0.05±0.01***	0.17±0.05**	225±66*	1.07±0.25***	303±99*	4.1±2.6	0.72±0.01**	238±15*	-63±21
	3.0	0.06±0.01***	0.11±0.02**	102±20***	0.72±0.02***	133±42**	5.7±1.6	0.75±0.01	313±9***	-107±14***
Two-way ANOVA										
Phosphate		**	***	***	***	***	*	***	*	NS
Thiobencarb		***	***	***	***	***	NS	***	***	***
PO_4+Thiobencarb		NS	NS	NS	NS	NS	NS	**	***	NS

(μ) Specific growth rate over days 2-8

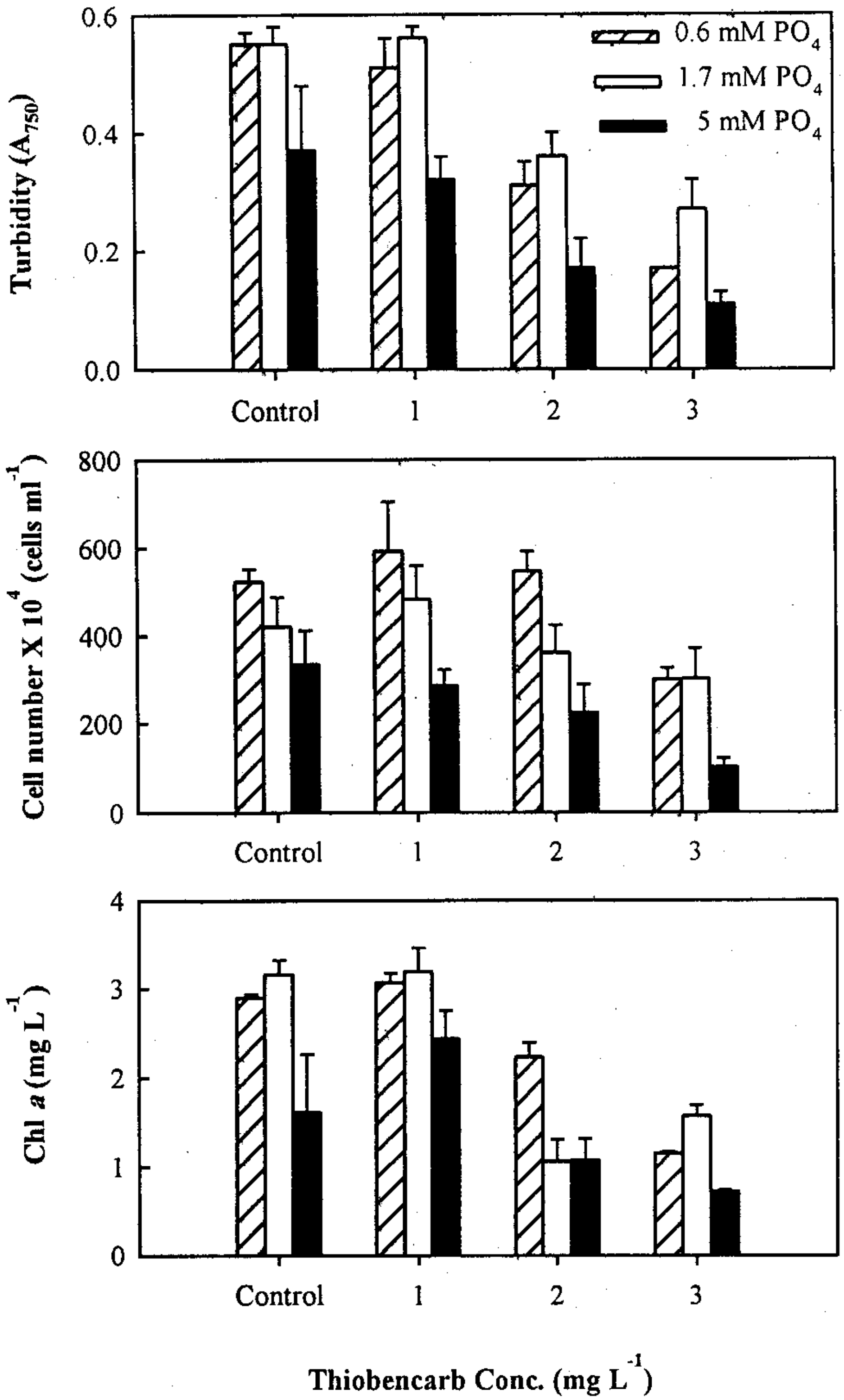

Fig. (15): Effect of phosphate interaction with thiobencarb on turbidity, cells number and Chl *a* content of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

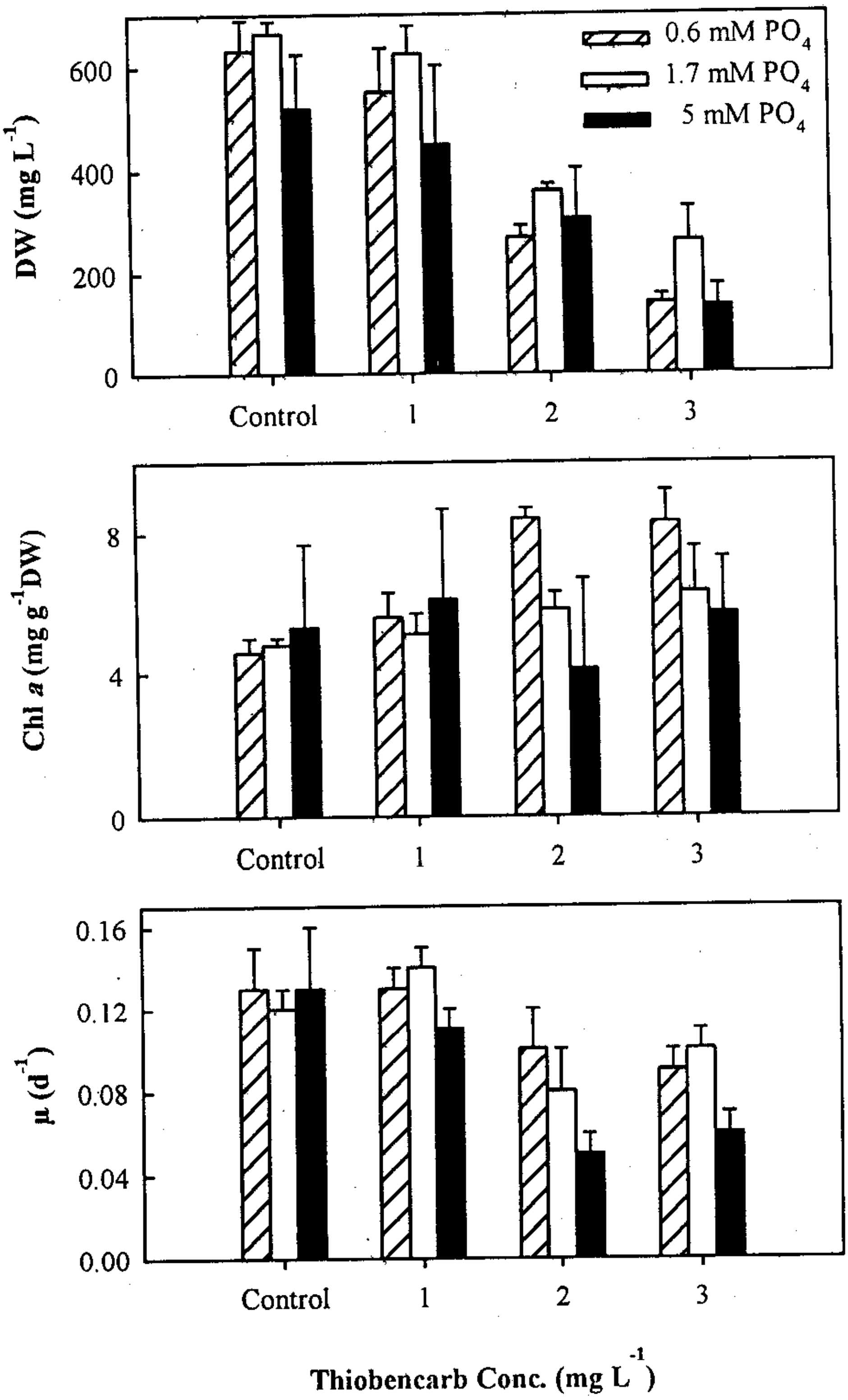

Fig. (16): Effect of phosphate interaction with thiobencarb on DW, Chl *a* (mg g^{-1}DW) and μ of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

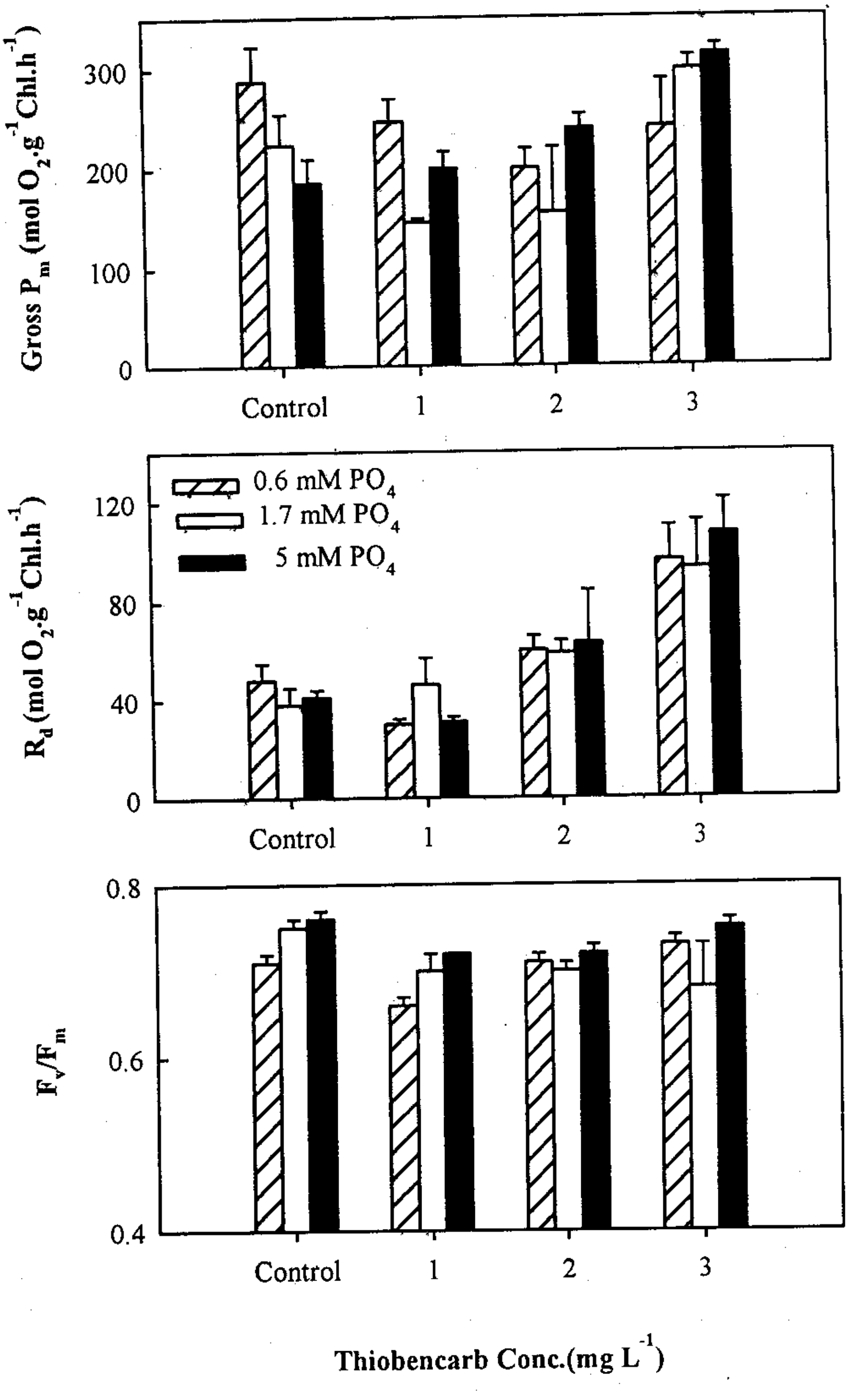

Fig. (17): Effect of phosphate interaction with thiobencarb on gross P_m, R_d and F_v/F_m of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

2-Phosphate effect on thiobencarb toxicity to *Anabaena*

The effect of phosphate concentration on sensitivity of *Anabaena variabilis* to thiobencarb was studied under diazotrophic conditions in BG-11 medium lacking a combined nitrogen source. Two-way ANOVA revealed a significant primary effect of phosphate on all growth and photosynthetic variables and a significant primary effect of thiobencarb on turbidity, Chl *a* and DW yields, Chl *a* (mg g^{-1} DW) and F_v/F_m (Table, 22). Phosphate and thiobencarb interaction significantly affected *Anabaena* specific growth rate (μ, days 2-6), turbidity and DW yields, Chl *a* (mg g^{-1} DW) and gross P_m^{Chl}. Comparing thiobencarb treatments within phosphate levels, specific growth rate (μ) was not consistently related to thiobencarb concentration, but turbidity, Chl *a* and DW yields significantly decreased with increasing thiobencarb concentration (Table, 22). F_v/F_m had no significant differences with respect to the control at all thiobencarb treatments, but it is highly affected by phosphate level (Fig. 20). Gross P_m^{Chl} & R_d^{Chl} nonsignificantly affected by thiobencarb, while significantly affected by phosphate level (Fig. 20). At 0.06 mM phosphate gross P_m^{Chl} tended to decrease its values lower than at the highest phosphate levels which mean that low phosphate concentration increase the inhibitory effect, while the highest level decrease it.

Table (22): Growth and photosynthetic parameters of *Anabaena variabilis* on day 10 of phosphate and thiobencarb treatment period. Means ± SD (n=3). Results of Two-way ANOVA and Dunnett's one-sided comparison of treatments to controls at the same phosphate level indicate * P < 0.05; ** P < 0.01; *** P < 0.001; NS, not significant.

PO_4 mM	Thiobencarb mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* mg g^{-1} DW	F_v/F_m	Gross P_m mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$	R_d mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$
0.06	Control	0.21±0.01	0.95±0.02	1.91±0.13	420±30	4.6±0.2	0.42±0.02	373±38	-18±5
	1.0	0.18±0.01	0.33±0.02***	1.26±0.05***	193±8***	6.5±0.0*	0.46±0.03	434±37	-22±28
	2.0	0.22±0.06	0.26±0.00***	1.22±0.14***	200±35***	6.3±1.6	0.40±0.03	318±55*	-36±3
	3.0	0.18±0.05	0.26±0.02***	1.26±0.09***	177±13***	7.1±0.7**	0.38±0.01	316±60*	-34±4
0.18	Control	0.17±0.02	0.63±0.02	2.30±0.22	247±2	9.3±0.8	0.48±0.01	307±53	-40±8
	1.0	0.12±0.02**	0.39±0.02***	1.36±0.17***	243±6	5.6±0.6***	0.48±0.02	296±84	-48±21
	2.0	0.13±0.02**	0.21±0.01***	1.43±0.05***	149±6***	9.6±0.2	0.45±0.04	439±77*	-35±21
	3.0	0.16±0.00	0.21±0.01***	1.53±0.15***	161±5***	9.5±0.7	0.39±0.04*	405±16	-26±17
0.53	Control	0.13±0.03	0.87±0.03	1.85±0.19	396±17	4.7±0.6	0.39±0.01	694±48	-44±24
	1.0	0.17±0.03	0.33±0.01***	1.23±0.08***	224±4***	5.5±0.3	0.42±0.01	473±87*	-77±19
	2.0	0.17±0.05	0.27±0.03***	1.25±0.18***	212±4***	5.9±0.7	0.38±0.02	503±120	-70±24
	3.0	0.23±0.01*	0.27±0.01***	1.26±0.08***	213±21***	6.0±0.9	0.37±0.06	486±125*	-80±19
Two-way ANOVA									
Phosphate		***	***	***	***	***	*	***	***
Thiobencarb		NS	***	***	***	***	***	NS	NS
PO_4+ Thiobencarb		*	***	NS	**	***	NS	**	NS

(μ) Specific growth rate over days 2-6

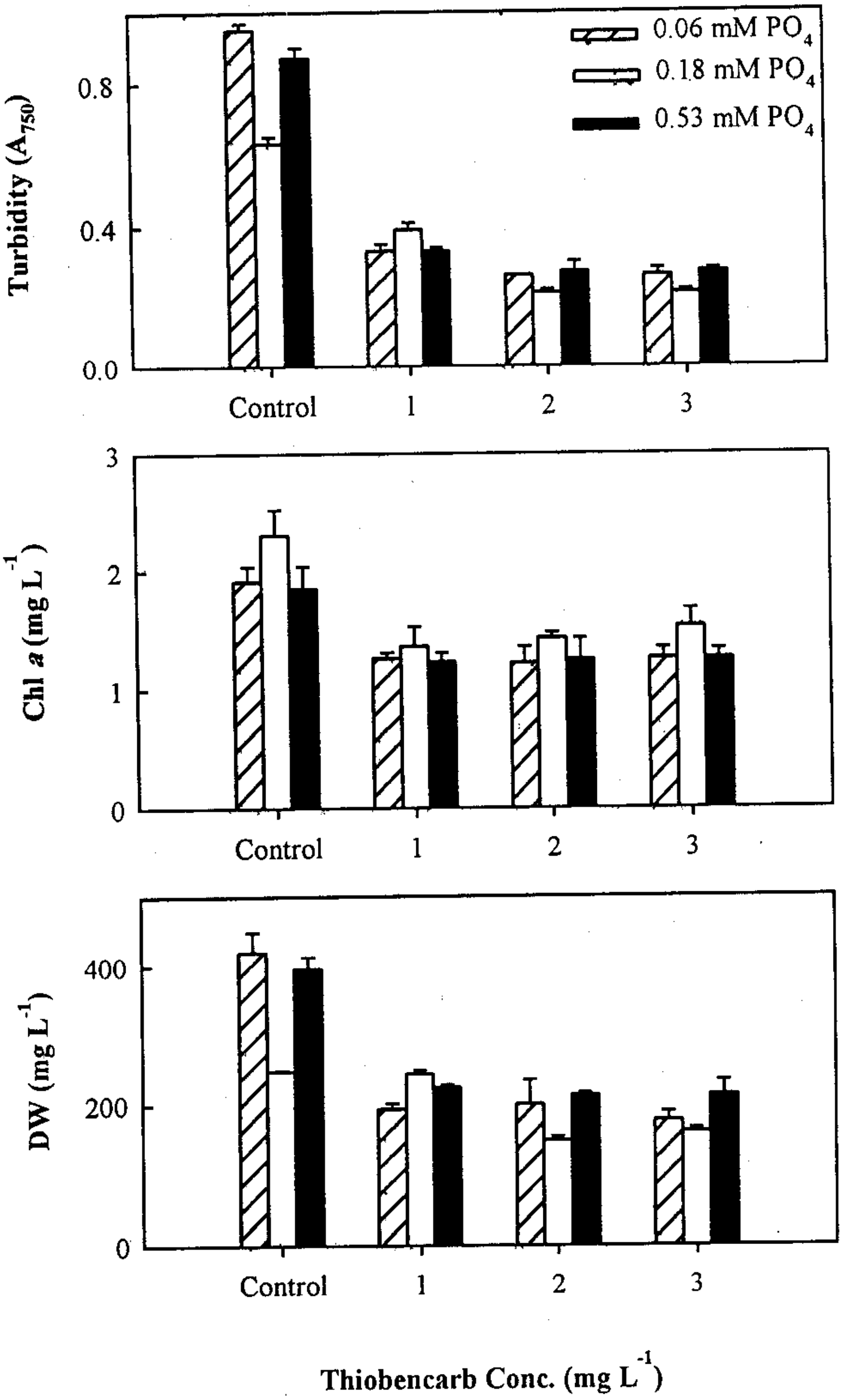

Fig. (18): Effect of phosphate interaction with thiobencarb on turbidity, Chl *a* content and DW of *Anabaena variabilis* after 10 days incubation. Means ± SD (n=3)

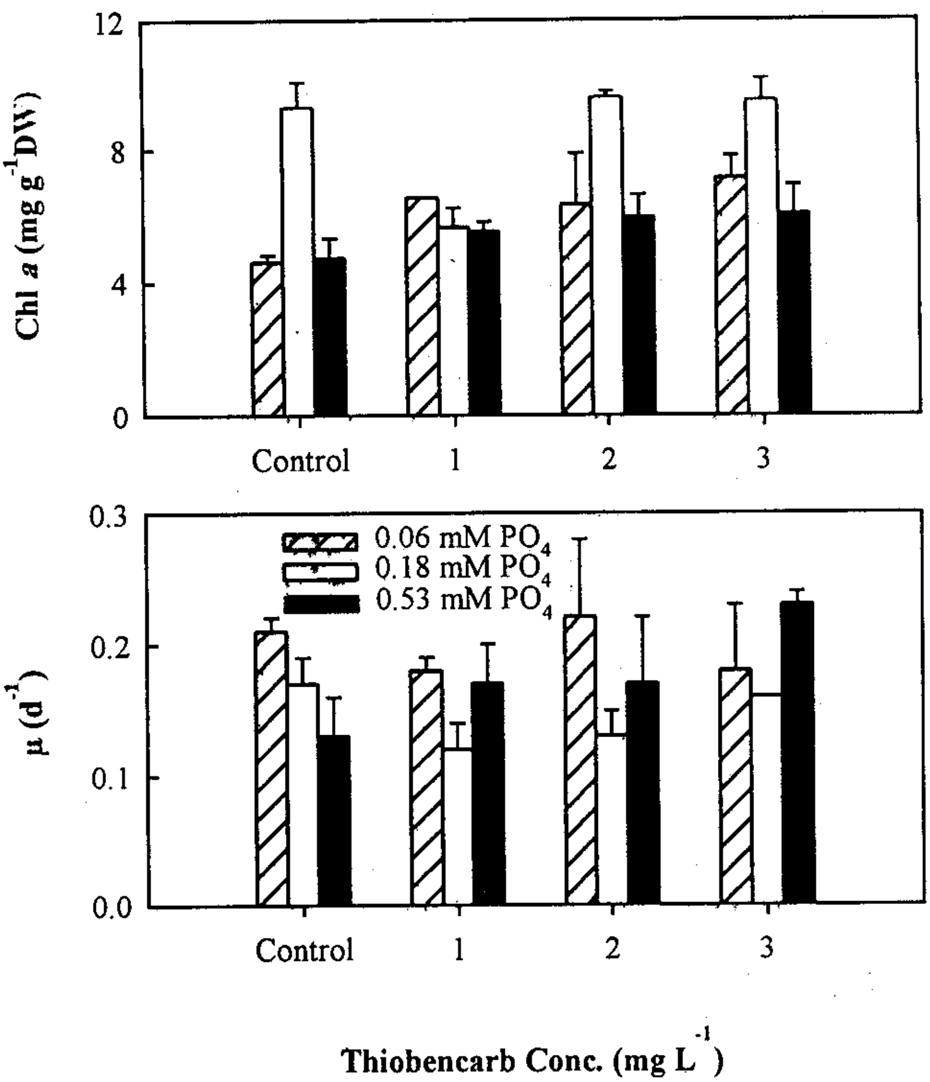

Fig. (19): Effect of phosphate interaction with thiobencarb on Chl/DW and μ of *Anabaena variabilis* after 10 days incubation. Means ± SD (n=3)

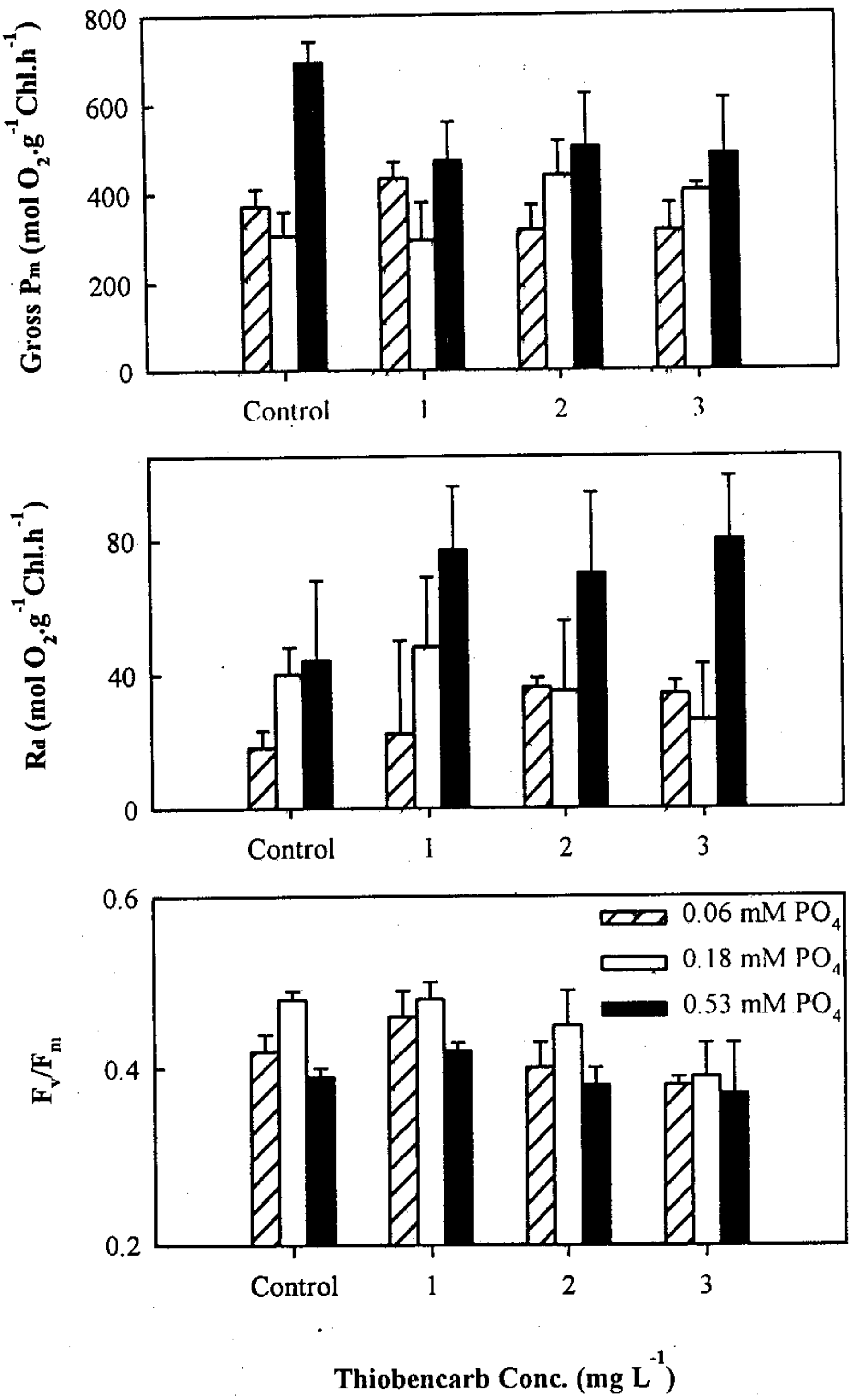

Fig. (20): Effect of phosphate interaction with thiobencarb on gross P_m, R_d and F_v/F_m of *Anabaena variabilis* after 10 days incubation. Means ± SD (n=3)

3-Phosphate effect on pendimethalin toxicity to *Protosiphon*

To test the effect of phosphate concentration on the sensitivity of *Protosiphon* to pendimethalin, different phosphate concentrations were conducted to BBM media with constant nitrate level (3 mM). Two-way ANOVA revealed that turbidity, cell number, Chl *a* and DW yields and F_v/F_m were significantly affected by phosphate, while all variables except Chl *a* (mg g^{-1} DW) were significantly affected by pendimethalin. Phosphate and pendimethalin interaction significantly affected all biomass yields (Table, 23). Comparing pendimethalin treatments within phosphate levels, specific growth rate (μ, days 2-8), turbidity, cells number, Chl *a* and DW yields decreased continuously with increasing pendimethalin concentration (Table, 23). High phosphate level (8.5 mM) reduced turbidity, cells number, Chl *a* and DW yields, as previously observed in the thiobencarb experiment, again confirming the detrimental effect of N:P<1 on *Protosiphon botryoides*. Biomass yields were inversely related to both phosphate and pendimethalin concentrations (Figs 21 & 22). Chl *a* (mg g^{-1} DW) and in general F_v/F_m were unaffected by pendimethalin. Gross P_m^{Chl} significantly increased at 1 mg L^{-1} pendimethalin at all phosphate levels, while R_d^{Chl} significantly increased only at 8.5 mM phosphate.

Table (23): Growth and photosynthetic parameters of *Protosiphon botryoides* on day 16 of phosphate and pendimethalin treatment period. Means ± SD (n=3). Results of Two-way ANOVA and Dunnett's one-sided comparison of treatments to controls at the same phosphate level indicate * P < 0.05; ** P < 0.01; *** P < 0.001; NS, not significant.

PO_4 mM	Pendimethalin mg L^{-1}	μ^{Chl} d^{-1}	Turbidity A_{750}	Cells count $\times 10^4$ ml^{-1}	Chl *a* mg L^{-1}	DW mg L^{-1}	Chl *a* mg g^{-1} DW	F_v/F_m	Gross P_m mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$	R_d mol $O_2 \cdot g^{-1} chl \cdot h^{-1}$
0.3	Control	0.13±0.02	0.31±0.02	260±26	2.92±0.29	404±34	7.3±1.0	0.79±0.01	51±10	-19±7
	0.25	0.13±0.05	0.13±0.05***	72±19***	1.24±0.44***	159±78***	8.2±1.1	0.80±0.01	182±45**	-46±21
	0.5	0.06±0.03*	0.08±0.02***	37±6***	0.74±0.26***	105±55***	7.8±3.0	0.73±0.05*	204±74**	-71±39
	1.0	0.05±0.02*	0.06±0.02***	23±9***	0.54±0.17***	63±18***	8.8±1.8	0.77±0.02	219±34**	-86±56
1.7	Control	0.12±0.03	0.26±0.01	332±10	2.20±0.25	287±94	8.4±3.4	0.77±0.01	100±17	-27±8
	0.25	0.08±0.03	0.13±0.02***	92±34***	1.11±0.14***	155±38*	7.4±1.7	0.79±0.01	170±27	-27±2
	0.5	0.08±0.03	0.08±0.00***	38±5***	0.83±0.06***	94±5**	8.9±0.5	0.74±0.02	145±7*	-35±11
	1.0	0.08±0.02	0.05±0.01***	25±6***	0.50±0.04***	56±19***	9.6±3.1	0.75±0.03	183±32**	-86±67
8.5	Control	0.13±0.03	0.16±0.02	137±24	1.32±0.15	171±11	7.8±1.4	0.79±0.00	131±9	-20±15
	0.25	0.08±0.02**	0.09±0.00***	62±26***	0.95±0.05**	97±3***	9.8±0.5	0.80±0.01	179±33	-69±25*
	0.5	0.06±0.01***	0.07±0.01***	33±6***	0.72±0.06***	73±2***	9.8±1.0*	0.78±0.01	148±8	-31±10
	1.0	0.08±0.00**	0.04±0.01***	14±7***	0.41±0.10***	53±8***	7.7±1.1	0.78±0.01	220±51**	-75±27*
Two-way ANOVA										
Phosphate		NS	***	***	***	***	NS	*	NS	NS
Pendimethalin		***	***	***	***	***	NS	***	***	**
PO_4+Pendimethalin		NS	***	***	***	**	NS	NS	NS	NS

(μ) Specific growth rate over days 2-8

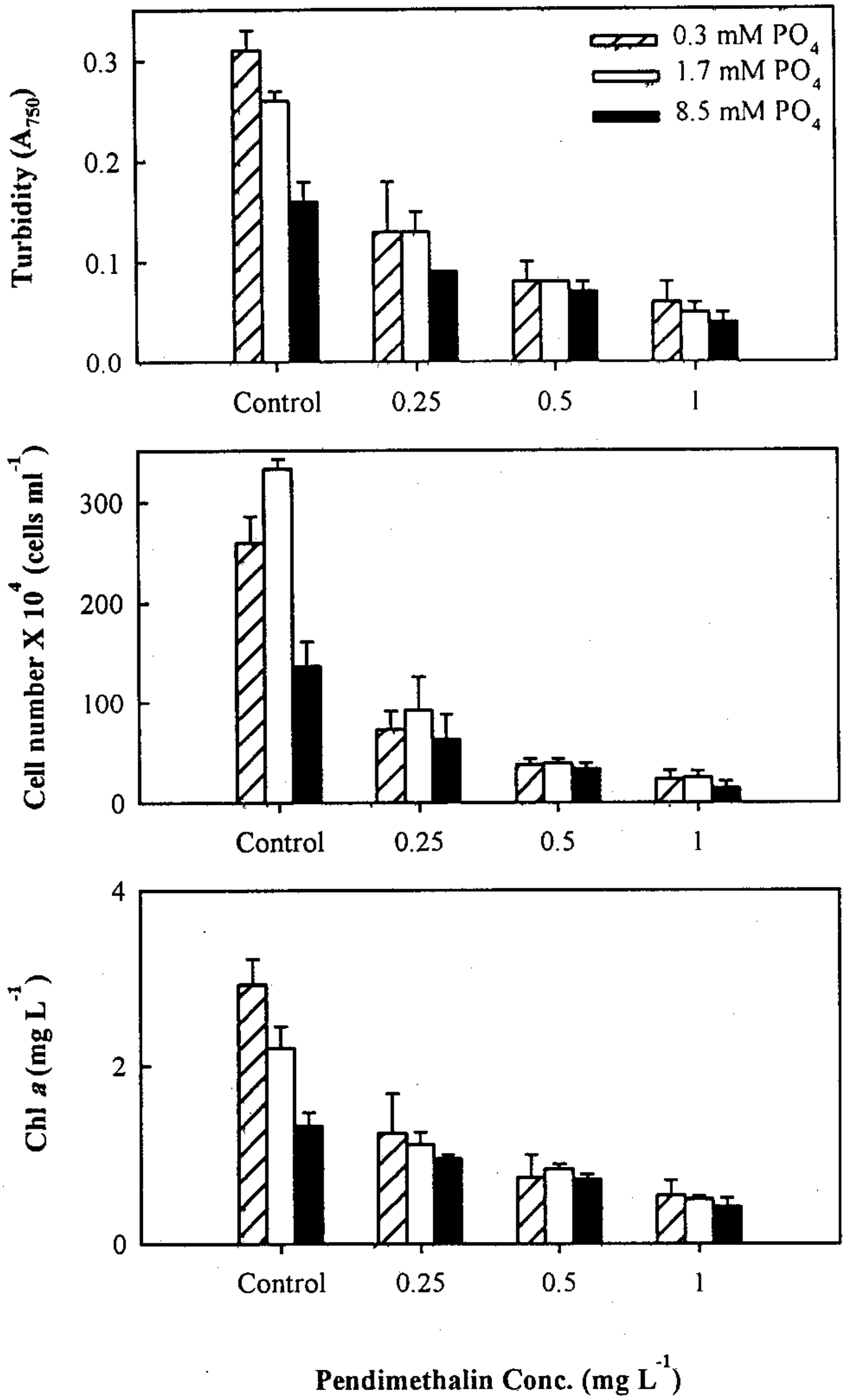

Fig. (21): Effect of phosphate interaction with pendimethalin on turbidity, cells number and Chl *a* content of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

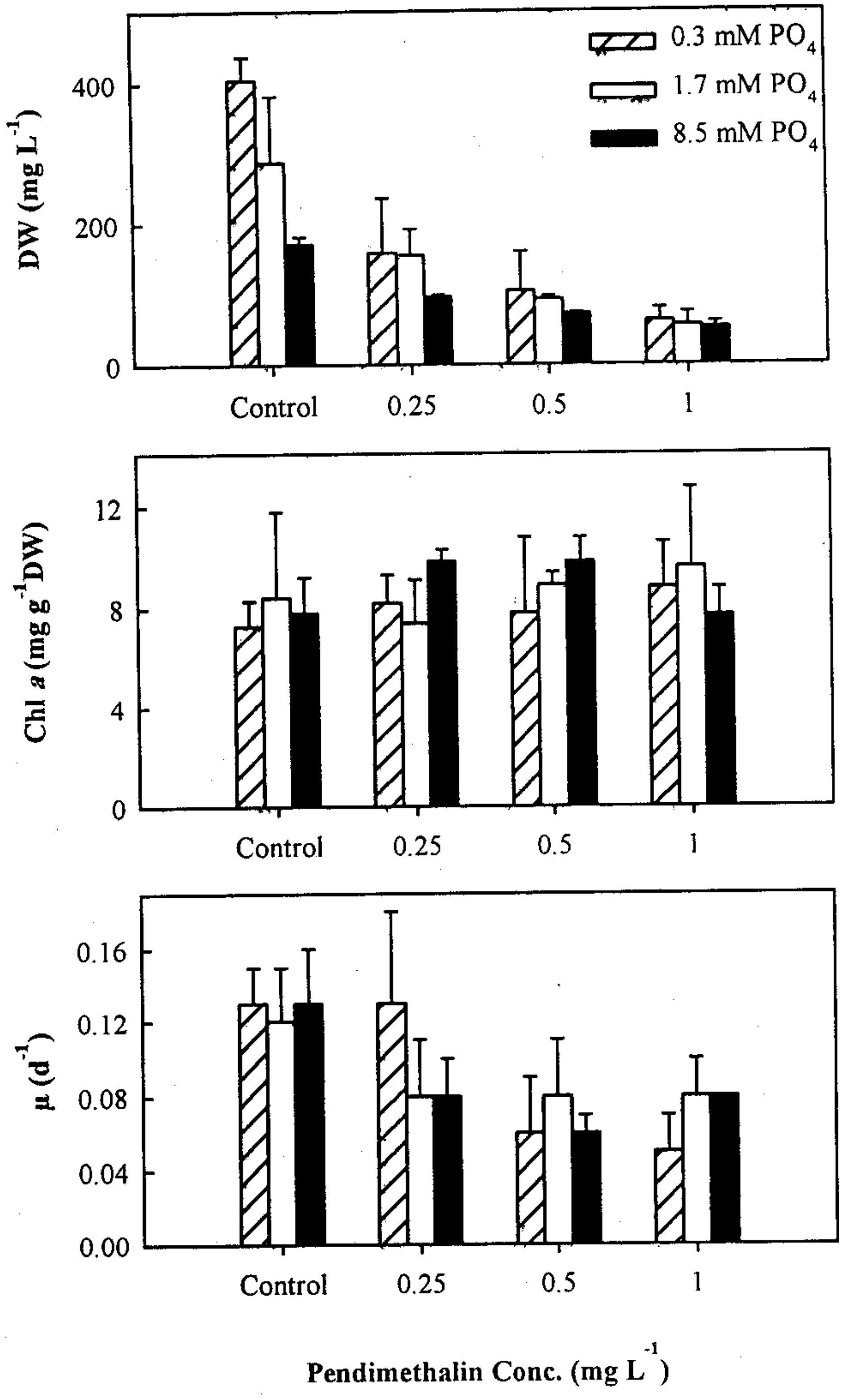

Fig. (22): Effect of phosphate interaction with pendimethalin on DW, Chl *a* (mg g^{-1}DW) and μ of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

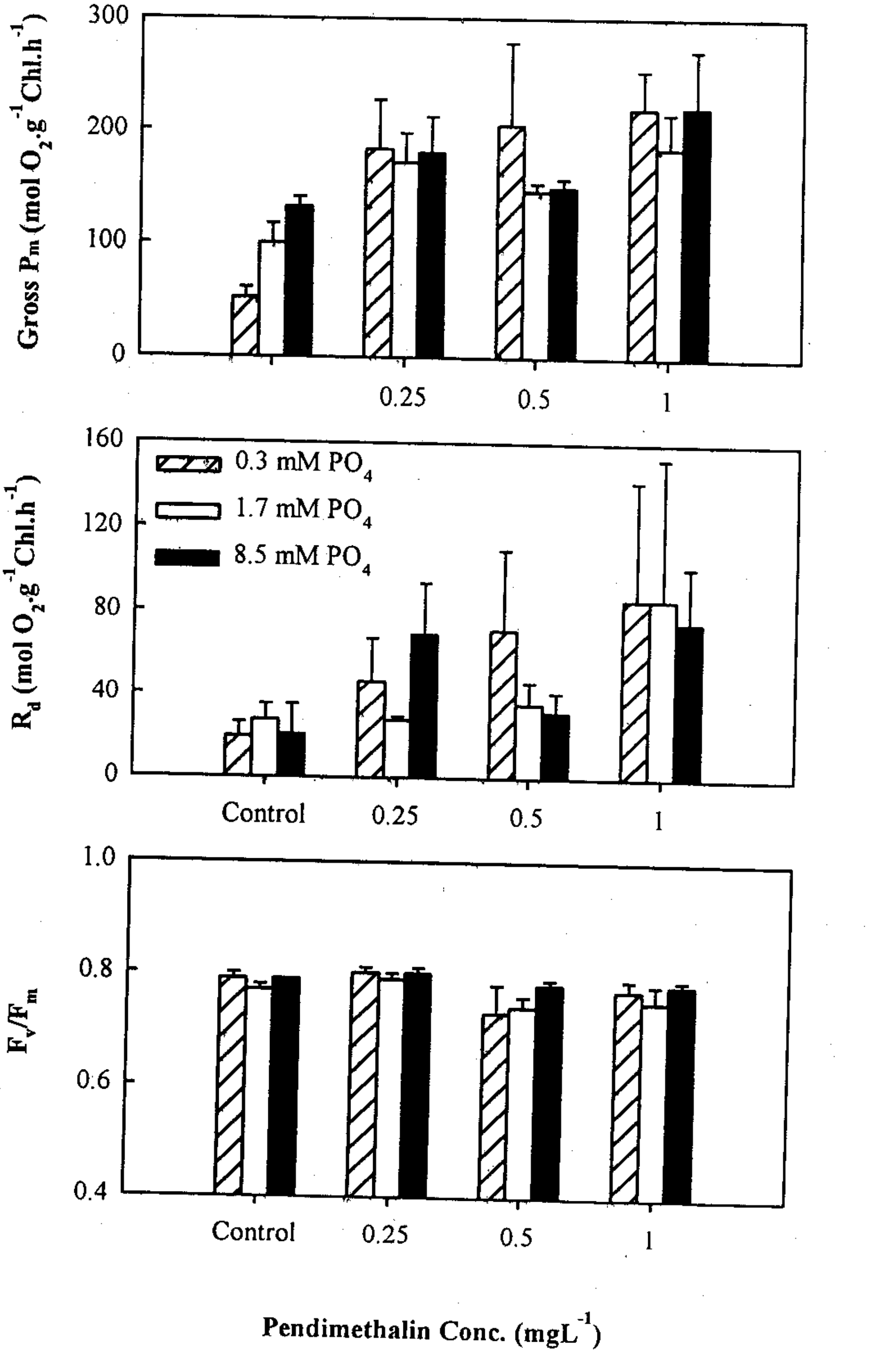

Fig. (23): Effect of phosphate interaction with pendimethalin on gross P_m, R_d and F_v/F_m of *Protosiphon botryoides* after 16 days incubation. Means ± SD (n=3)

IV-Herbicides uptake by algae

Uptake of herbicide by algae was determined by measuring its residue in culture medium at the end of incubation period. The method used to quantify thiobencarb uptake did not distinguish between absorption and adsorption to the algal cells, therefore the term uptake is used to designate the combination of these two processes (**Neumann** *et al.*, **1987; Manthey** *et al.*, **1993**). Different thiobencarb concentrations were added to uninoculated culture media as control samples and to algal cultures placed under the optimum growth conditions to determine the rate of herbicide loss through biotic and abiotic processes.

1-Thiobencarb uptake by *Protosiphon*

The entire content of *Protosiphon* cultures and control media (without algal cells) were harvested after 16 days to show the partitioning of thiobencarb residue. Residual thiobencarb concentrations in control medium and culture medium, but not in cells, increased progressively with increasing initial thiobencarb addition (Table 24 & Fig. 24). About half of the thiobencarb was detected after 16 days in sterile control media, but ≤5% remained in algal culture media and ≤2% in the tissue. The decrease may be due to either degraded, volatilized or adhered to the culture flasks.

2-Thiobencarb uptake by *Anabaena*

The entire content of *Anabaena* cultures and control media (without algal cells) were harvested after 10 days to show the partitioning of thiobencarb residue. Residual thiobencarb concentrations in control medium and culture medium increased progressively with increasing initial thiobencarb addition, and residual thiobencarb concentrations were negligible in cells (Table 24 & Fig 24). About one-third of the thiobencarb was detected after 10 days in sterile control media, but ≤16% remained in algal culture media and ≤2% in the cells. The decrease may be due to either degradation, volatilization or adhering to the culture flasks. Generally, maximum uptake level was attained in the presence of low thiobencarb concentration where growth measurements for both of *Protosiphon* and *Anabaena* were at their highest values.

Table (24): Residual thiobencarb concentration (mg L^{-1}) in *Protosiphon botryoides* and *Anabaena variabilis* cultures and uninoculated control media. Means ± SD (n=3). In all thiobencarb treatments, culture media and cells contained significantly ($P < 0.01$) less thiobencarb residue than control media without algae. N.D., not detected.

	Protosiphon botryoides		
Initial thiobencarb / Residual thiobencarb	**1 mg L^{-1}**	**2 mg L^{-1}**	**3 mg L^{-1}**
Control media	0.411± 0.219	1.255± 0.205	1.544± 0.199
Culture media	0.009± 0.002	0.023± 0.009	0.169± 0.274
Cells	0.022± 0.013	0.028± 0.014	0.022± 0.014
	Anabaena variabilis		
Control media	0.346± 0.033	0.792± 0.115	1.073± 0.249
Culture media	0.004± 0.002	0.29± 0.023	0.484± 0.028
Cells	0.021± 0.001	0.005± 0.005	0.001± 0.000

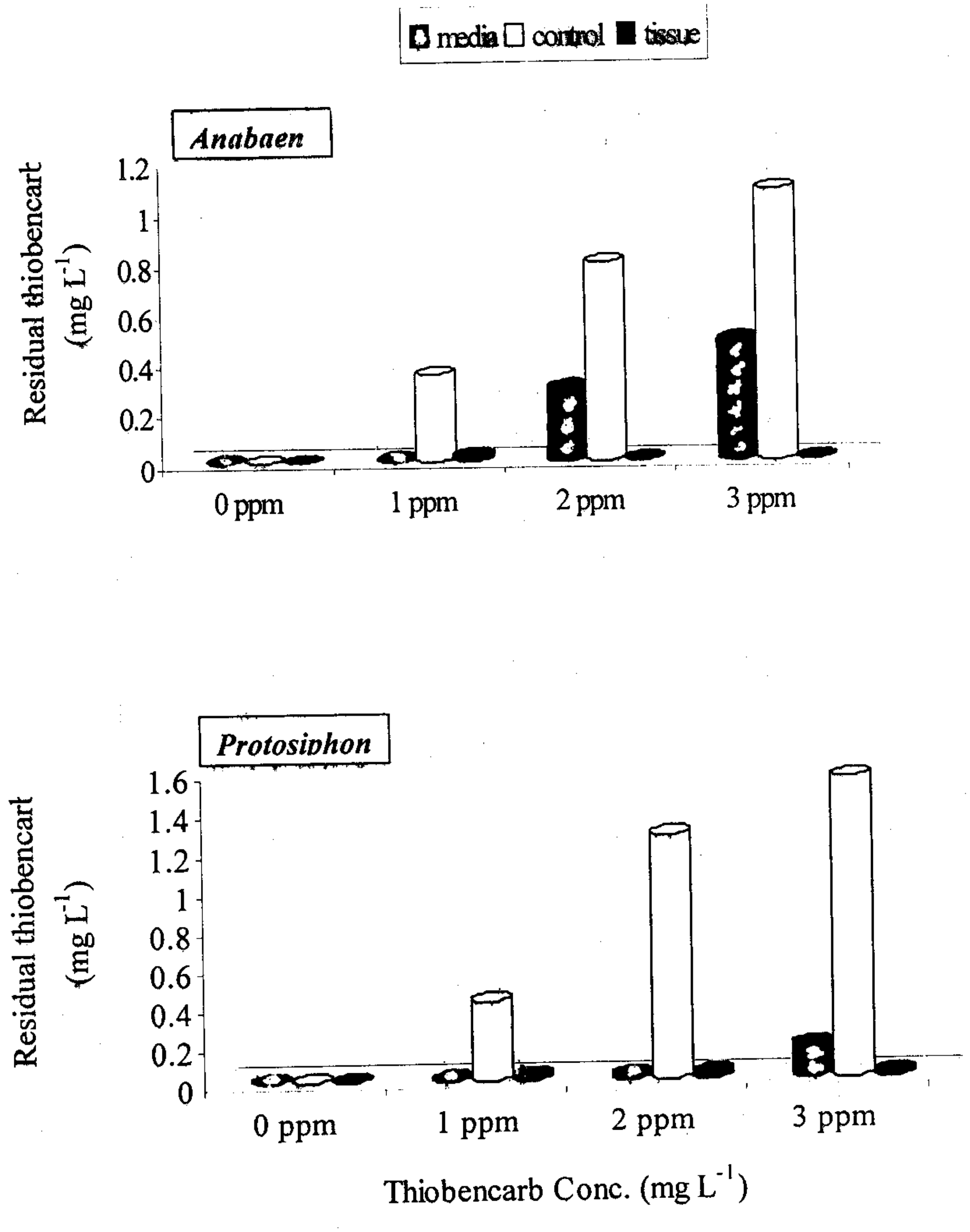

Fig (24): Residual thiobencarb concentrations extracted from treated *Protosiphon* and *Anabaena* culture media, tissues and its control.