REPORT HEADERS.

PROJECT NO. RP-14

ANNUAL REPORT
COMPREHENSIVE RESEARCH ON RICE
January 1, 2009 - December 31, 2009

PROJECT TITLE: Assessing alternative methods for managing algae in California rice fields.

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OBJECTIVES AND EXPERIMENTS CONDUCTED, BY LOCATION, TO ACCOMPLISH OBJECTIVES:

Objective 1. *Determine the effects of rice field water quality parameters and algaecides on growth of Nostoc spongiaeforme isolated from California rice fields under laboratory conditions.*

We now have *Nostoc spongiaeforme* from rice fields growing in a unialgal liquid culture in flasks at the USDA ARS Exotic & Invasive Weeds Research Unit facility in Davis, California. We also have considerable data on water quality parameters (chloride, sulfate, calcium, magnesium, sodium, and potassium) for rice field water samples. This information will be used in experiments where the effects of selected water quality parameters, e.g., sodium, on *N. spongiaeforme* can be tested. For example, *N. spongiaeforme* will be exposed to a range of sodium concentrations at 25 C, 13:11 h light:dark cycle, 400 μM m^{-2} s^{-1} for one week. There will be four replicate flasks at each of the following sodium concentrations: 0, 8.6, 25.8, 43.0, 60.2, 77.4, and 94.6 mg L^{-1}. These sodium concentrations are based on the water quality data which indicate that sodium concentrations in rice field water ranged from 3 to 96 mg L^{-1}. After one week, 10 ml of culture medium will be collected and the chlorophyll content determined following extraction with DMSO. The logarithms (base 2) of starting and ending chlorophyll concentrations will be used in linear regression versus time to determine the growth rate, yielding growth rates which have units of doublings day^{-1}. The effects of the tested parameter will be assessed using graphical and statistical methods (liner or nonlinear regression). All statistical calculations will be done using SAS software.

We will use this approach and previously described outdoor “bucket” experiments to evaluate the algicidal properties of new aquatic herbicides that may enter the market.

Objective 2: Determine the effectiveness of four phosphorus fertilizer application methods for reducing algal growth.

Field Experiment:

Data from the 2008 field experiment indicates that algal growth was limited when the phosphorus fertilizer was applied 30 days after the initial flooding of the field. We need to obtain additional results from a greater variety of fields both geographically and in terms of spring soil phosphorus levels. We have met with growers. At least one of them has agreed to apply phosphorus containing fertilizer in the following manner: phosphate applied 30 days after flooding; surface applied liquid phosphate fertilizer followed by a roller; phosphate fertilizer applied in the spring and incorporated into the soil as part of the spring ground work up; and phosphate fertilizer applied in the fall and incorporated into the soil as part of the spring ground work up. Following flooding, we will sample the fields for algal abundance at 2 to 3 day intervals for up to four weeks using a GPS camera. We will also collect water samples for phosphate analysis. Biomass samples will be collected and processed as described above. We will also use filtered rice field water in bioassay experiments to determine if phosphorus is limiting to the growth of *N. spongiaeforme*. We will compare algal biomass in the four phosphorus fertilizer application methods to determine the effectiveness of this approach in a greater diversity of rice fields than we used in 2008. Where appropriate, data will be analyzed statistically with analysis of variance.

Our ability to accomplish this experiment is dependent upon finding additional growers willing to cooperate in this experiment, but as of this date we have relatively strong commitments from at least one grower.

SUMMARY OF 2009 RESEARCH (major accomplishments), BY OBJECTIVE:

Please note some experimental designs and procedures were modified from the original proposal as we were not always able to obtain field sites for some of the proposed work.

Objective 1. *Determine the effects of rice field water quality parameters and algaecides on growth of Nostoc spongiaeforme isolated from California rice fields under laboratory conditions.*

We conducted two laboratory experiments with various concentration of Hydrothol 191 and *N. spongiaeforme*. Flasks were randomly assigned to one of the following Hydrothol 191 treatment levels: 0, 0.1, 0.3, 0.5, 1, 3, 5, 6, 8, and 10 mg L^{-1} (ppm, parts per million). The results of these experiments were similar. Data from one of them are shown in Figures 1. *N. spongiaeforme* growth rates declined significantly when the Hydrothol 191 concentration was 0.3 mg L^{-1} or higher (Table 1).

We conducted a total of 12 field experiments covering a range of Hydrothol 191 concentrations, including values greater than the highest concentration listed for use on the Hydrothol 191 label which is 5 ppm (parts per million). Representative results from three of these experiments with *N. spongiaeforme* shown in Figures 2 and 3. Based on the chlorophyll reflectance measurements Hydrothol 191 did not have a detrimental effect on the algae until the concentration exceeded 6 ppm (Table 2). The effect was noticeable after 2 or 3 days exposure at these concentrations. However, *N. spongiaeforme* chlorophyll reflectance began to increase again, indicating that the algae were recovering from the effects of Hydrothol 191. The effect of Hydrothol 191 exposure was reflected in final algal dry weights which were significantly reduced in only two experiments which involved Hydrothol 191 concentrations $\geq$ 6 ppm (Figure 4 and Table 3). However, reduced dry weights were only observed for algae grown in water from one field and not the other, suggesting that water quality characteristics may differ between these fields. The initial dry weights for these experiments were 0.71 g with 95% confidence limits of 0.57 to 0.85 g. This is equivalent to a mean biomass value of 9.96 g m^{-2} with confidence limits of 8.01 to 11.92 g m^{-2}. Thus, the amounts of cyanobacteria/algae used to start these experiments were representative of the amounts of cyanobacteria/algae present in rice fields which averaged 12.97 g m^{-2} with 95% confidence limits of 10.10 to 15.84 g m^{-2} (see below).

In addition we conducted 6 similar experiments using the green alga, *Hydrodictyon* sp. Algal material was collected from a rice field where we have previously observed it to grow in and cause a considerable problem to the grower. These experiments were conducted outdoors in Davis, California at the Exotic and Invasive Weeds Research Unit facilities. In this case the algae were grown in non-chlorinated ground water instead of rice field water. *Hydrodictyon* chlorophyll reflectance showed a similar initial decrease upon exposure to Hydrothol 191. This was most pronounced at Hydrothol 191 concentrations above 5 ppm. *Hydrodictyon* chlorophyll reflectance did recover by the end of the experiment (Figures 5 and 6, Table 4). Hydrodictyon dry weight after 7 days was also affected by the Hydrothol 191 treatments (Figure 7, Table 5). The initial dry weights for these experiments were 0.58 g with 95% confidence limits of 0.52 to 0.64 g. This is equivalent to a mean biomass value of 8.10 g m^{-2} with confidence limits of 7.29 to 8.92 g m^{-2}.

The results of these experiments indicate that *Hydrodictyon* was more susceptible to Hydrothol 191 than to another non-copper algaecide that we investigated previously. In that study, treatments of 22.5, 45, or 90 lbs $acre^{-1}$ of sodium carbonate peroxyhydrate (this compound releases hydrogen peroxide) were made to *Hydrodictyon* in field experiments. In those experiments summarized in the 2007 report to the California Rice Research Board, we found that there was no significant effect of the sodium carbonate peroxyhydrate treatments on either chlorophyll reflectance or algal dry weight.

In order to gain a better understanding of the interaction between Hydrothol 191 and *N. spongiaeforme*, we conducted two additional laboratory experiments. Flasks were randomly assigned to one of the following Hydrothol 191 treatment levels: 0, 0.1, 0.3, 3, and 8 mg L^{-1} (ppm, parts per million). One set of had the Hydrothol 191 treatments and 0.125 g L^{-1} of rice straw added to the culture medium. The results of one of these experiments are shown in Figure 8. In this case *N. spongiaeforme* growth rates were reduced at 0.3 ppm of Hydrothol 191, but not when rice straw was added to the culture medium, as indicated by the significant rice straw x Hydrothol 191 interaction term (Table 6).

This clearly indicates that the addition of rice straw has reduced the effect of Hydrothol 191 on *N. spongiaeforme*. It may be possible that rice straw and Hydrothol 191 interact either chemically or physically (i.e., by physical attachment) to render Hydrothol 191 in a form that is non-toxic to *N. spongiaeforme*. A second possibility is that the introduction of rice straw has also introduced bacteria or promoted the growth of bacteria that can breakdown Hydrothol 191. The major influence on Hydrothol 191 persistence in the field is microbial degradation. Either of these mechanisms could also explain the temporary (3 to 5 days) reduction in chlorophyll reflectance measured in the bucket experiments.

The results of these outdoor and laboratory experiments indicate that Hydrothol 191 did not consistently kill *N. spongiaeforme* even at concentrations greater than the maximum labeled rate, 5 ppm, however its effect on the green alga, *Hydrodictyon* or water net, was more pronounced. At present this algaecide is not labeled for use in California rice fields and it is not clear how it may fit into algal control strategies for these systems.

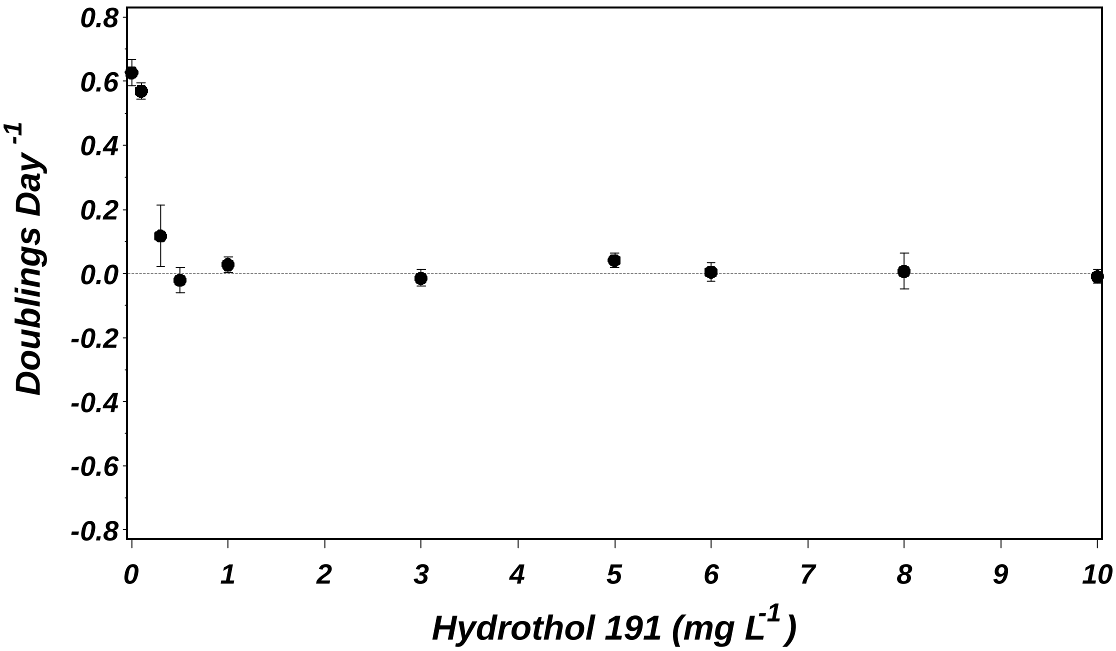
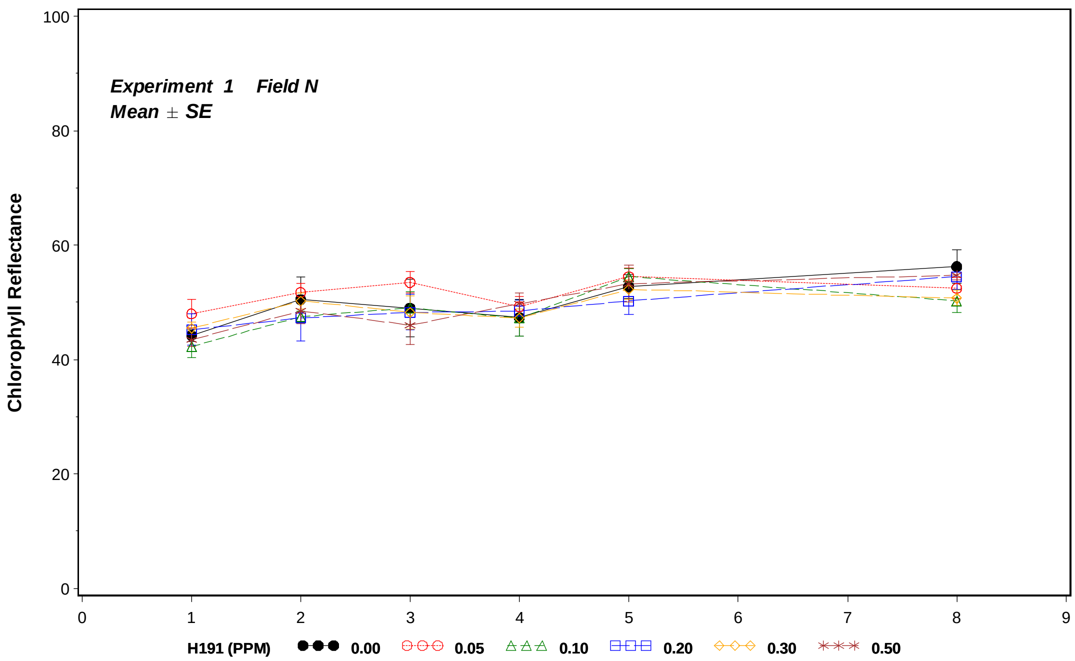


Figure 1. Effect of Hydrothol 191 algaecide on *Nostoc spongiaeforme* in laboratory culture. Plotted values are the mean ± 1 SE and are based on four replications.

Table 1. Analysis of variance results for *Nostoc spongiaeforme* growth rates versus various concentration of Hydrothol 191 (H191) in a growth chamber experiment. The H191 concentrations were: 0, 0.1, 0.3, 0.5, 1, 3, 5, 6, 8, and 10 mg L^{-1} (parts per million).

Experiment	Hydrothol 191 Range (PPM)	Site	Source	DF	SS	F-value	Prob.
1	0 - 10.0	Lab	H 191	9	2.23	13.38	< 0.0001
			Error	30	0.55		



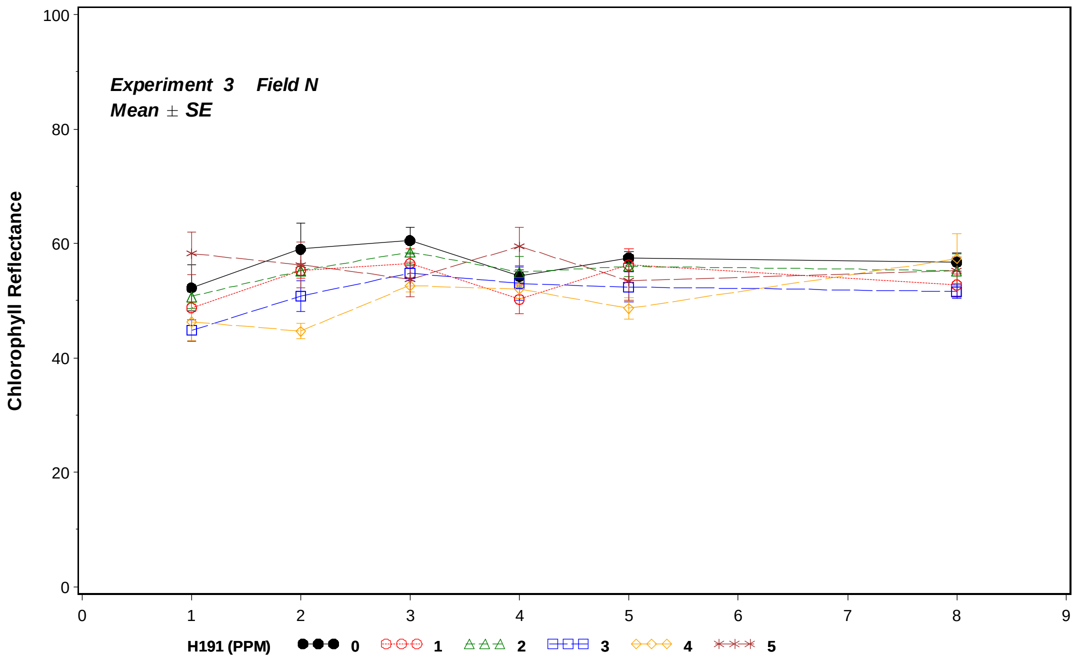


Figure 2. Chlorophyll reflectance measurements for field-collected algae (primarily *Nostoc*) exposed to various concentration of Hydrothol 191 algaecide (H191). Plotted values are based on four replications.

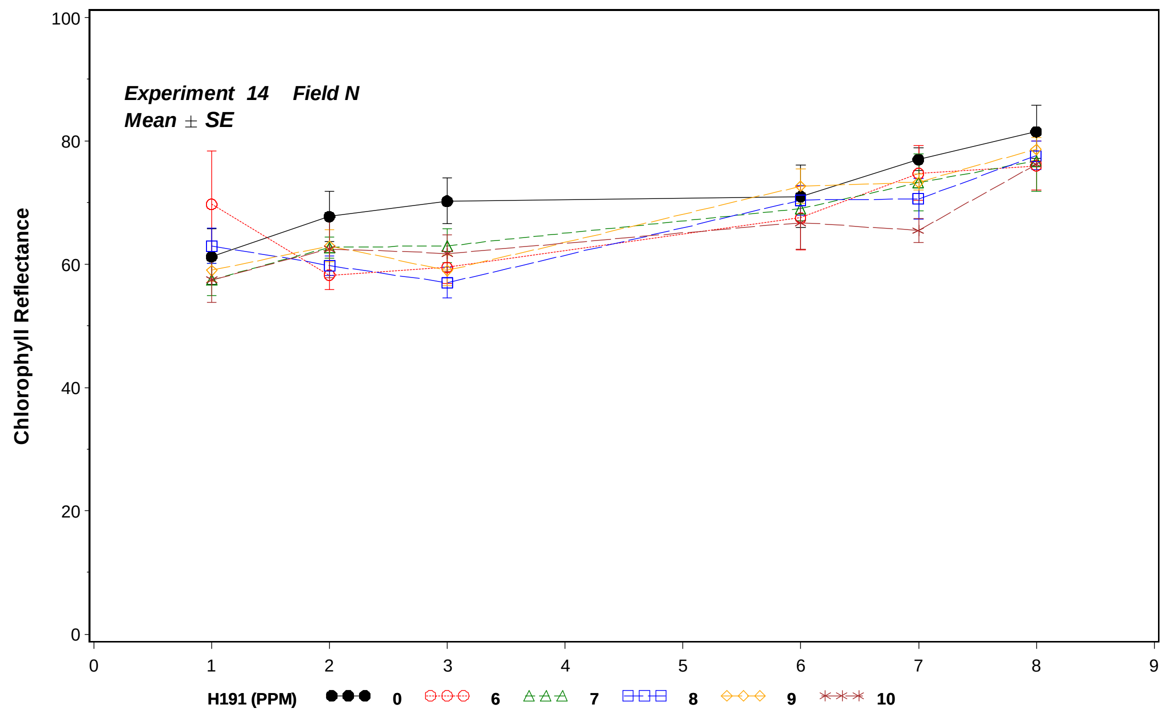
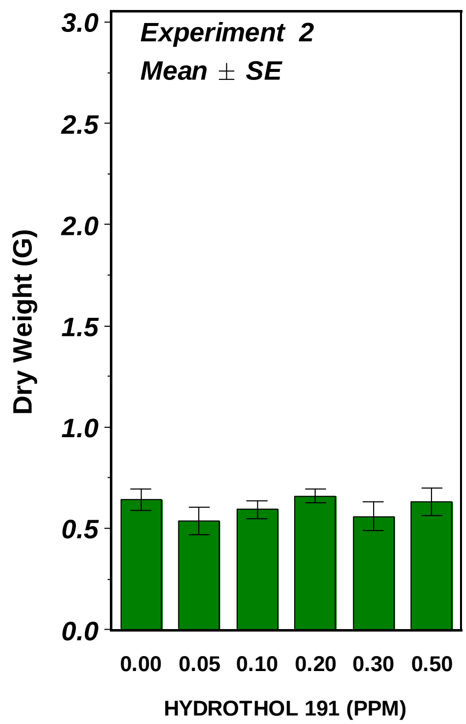
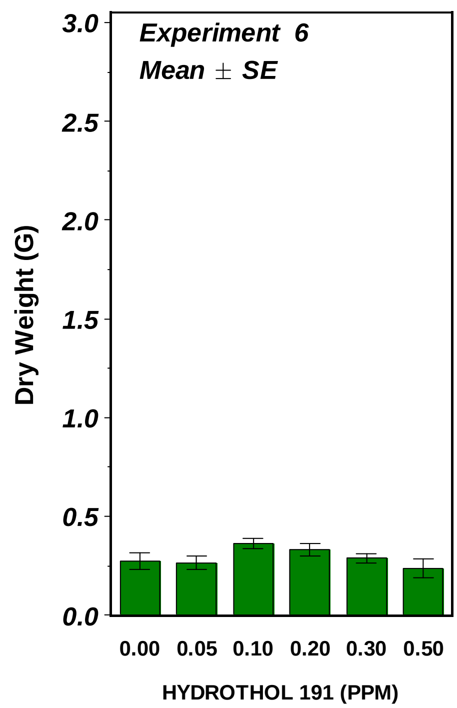


Figure 3. Chlorophyll reflectance measurements for field-collected algae (primarily *Nostoc*) exposed to various concentration of Hydrothol 191 algaecide (H191). Plotted values are based on four replications.

Table 2. Analysis of variance results for chlorophyll reflectance for each day that field-collected algae (primarily *Nostoc*) were exposed to various concentration of Hydrothol 191 (algaecide). The concentrations, "0 to 0.5 PPM" = 0, 0.05, 0.1, 0.2, 0.3, 0.5 PPM; "0 to 5" = 0, 1, 2, 3, 4, 5 PPM; and "0 to 10" = 0, 6, 7, 8, 9, 10 PPM (PPM = parts per million).

Experiment	Hydrothol 191 Range (PPM)	Field	Day	Source	DF	SS	F-value	Prob.
1	0 to 0.5	N	1	H 191	5	77.71	1.08	0.40
				Error	18	258.25		
			2	H 191	5	65.71	0.47	0.79
				Error	18	503.25		
			3	H 191	5	121.50	0.55	0.74
				Error	18	798.50		
			4	H 191	5	23.77	0.24	0.94
				Error	17	336.67		
			5	H 191	5	50.83	0.56	0.73
				Error	18	325.00		
			8	H 191	5	114.33	1.48	0.25
				Error	18	279.00		
3	0 to 5	N	1	H 191	5	476.16	2.58	0.06
				Error	18	664.47		
			2	H 191	5	444.24	2.60	0.06
				Error	18	615.72		
			3	H 191	5	166.74	1.71	0.18
				Error	18	351.22		
			4	H 191	5	198.46	1.44	0.26
				Error	18	494.50		
			5	H 191	5	183.34	1.48	0.25
				Error	18	446.62		
			8	H 191	5	102.97	0.96	0.47
				Error	18	384.87		
14	0 to 10	N	1	H 191	5	430.50	0.99	0.45
				Error	18	1561.50		
			2	H 191	5	217.91	1.19	0.35
				Error	18	658.05		
			3	H 191	5	450.83	2.71	0.05
				Error	18	598.50		
			6	H 191	5	90.34	0.31	0.90
				Error	18	1053.62		
			7	H 191	5	318.59	1.44	0.26
				Error	18	796.37		
			8	H 191	5	84.13	0.36	0.87
				Error	18	830.37		





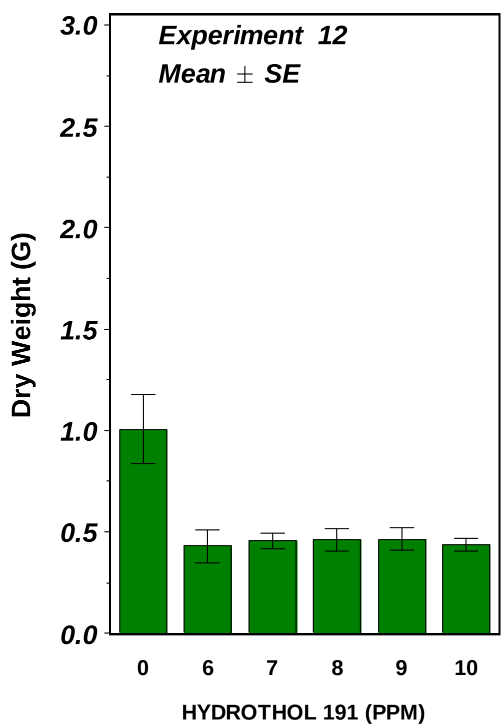
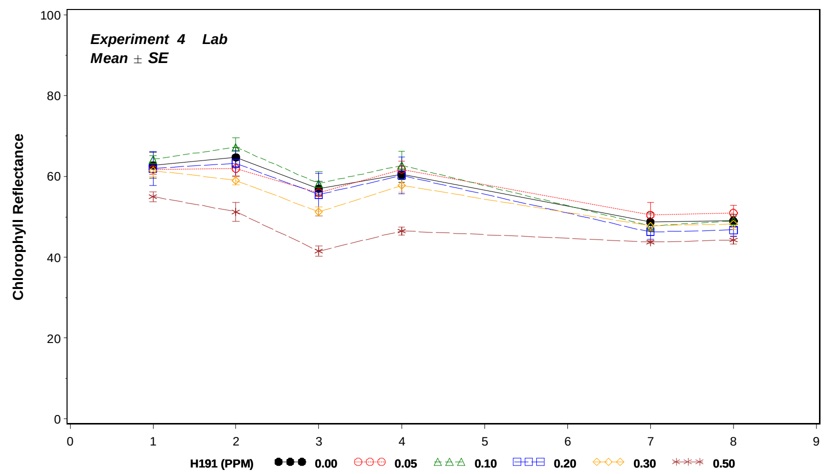


Figure 4. Algal dry weight measurements for field-collected algae (primarily *Nostoc*) exposed to various concentration of Hydrothol 191 algaecide for one week. Plotted values are based on four replications.

Table 3. Analysis of variance results for dry weight for field-collected algae (primarily *Nostoc*) exposed to various concentration of Hydrothol 191 (algaecide). The concentrations, “0 to 0.5 PPM” = 0, 0.05, 0.1, 0.2, 0.3, 0.5 PPM; “0 to 5” = 0, 1, 2, 3, 4, 5 PPM; and “0 to 10” = 0, 6, 7, 8, 9, 10 PPM (PPM = parts per million).

Experiment	Hydrothol 191 Range (PPM)	Field	Source	DF	SS	F-value	Prob.
2	0 to 0.5	Field R	H191	5	0.17	0.70	0.63
			Error	18	0.85		
5	0 to 5	Field R	H191	5	0.52	0.97	0.46
			Error	18	1.93		
12	0 to 10.0	Field R	H191	5	2.07	3.64	0.02
			Error	18	2.04		



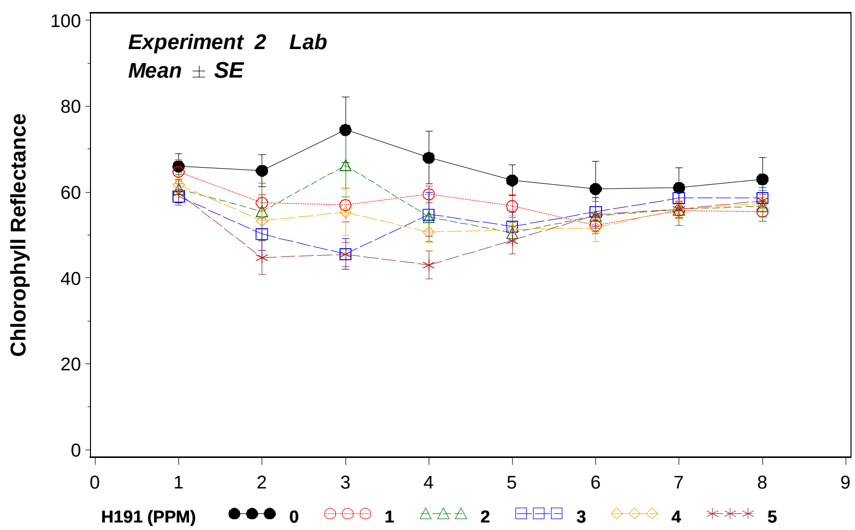


Figure 5. Chlorophyll reflectance measurements for field-collected algae (primarily *Hydrodictyon*) exposed to various concentration of Hydrothol 191 algaecide (H191). Plotted values are based on four replications.

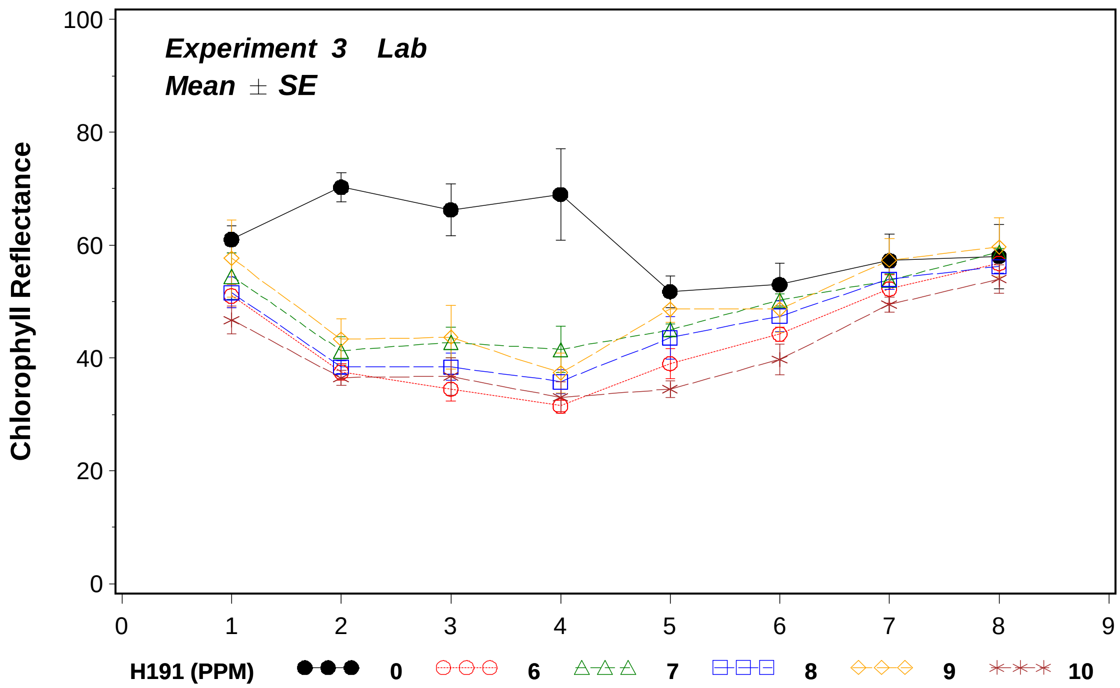


Figure 6. Chlorophyll reflectance measurements for field-collected algae (primarily *Hydrodictyon*) exposed to various concentration of Hydrothol 191 algaecide (H191). Plotted values are based on four replications.

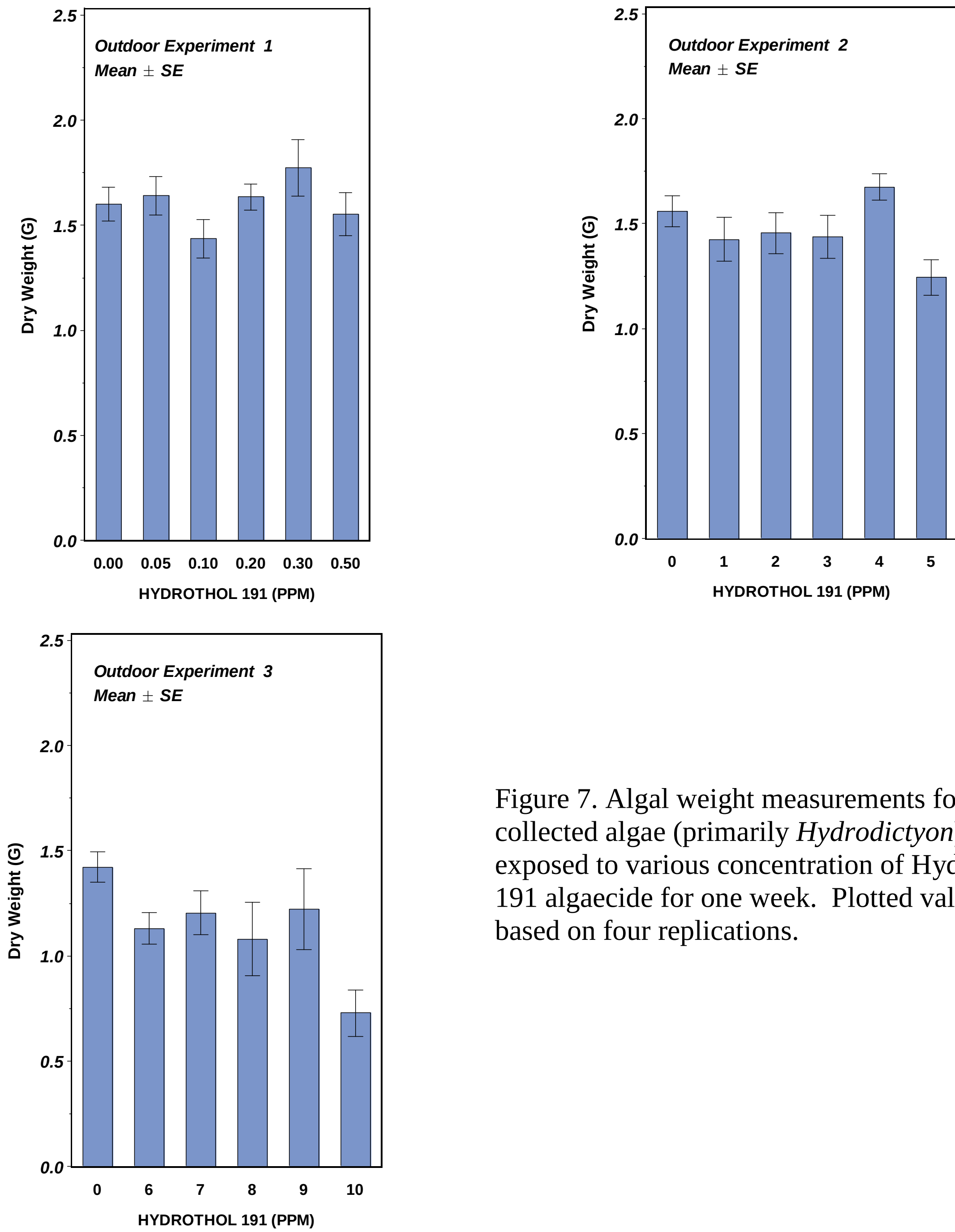


Figure 7. Algal weight measurements for field-collected algae (primarily *Hydrodictyon*) exposed to various concentration of Hydrothol 191 algaecide for one week. Plotted values are based on four replications.

Table 4. Analysis of variance results for chlorophyll reflectance for each day that field-collected algae (primarily *Hydrodictyon*) were exposed to various concentration of Hydrothol 191 (algaecide). The concentrations, “0 to 0.5 PPM” = 0, 0.05, 0.1, 0.2, 0.3, 0.5 PPM; “0 to 5” = 0, 1, 2, 3, 4, 5 PPM; and “0 to 10” = 0, 6, 7, 8, 9, 10 PPM (PPM = parts per million).

Experiment	Hydrothol 191 Range (PPM)	Site	Day	Source	DF	SS	F-value	Prob.
2	0 - 5.0	Lab	1	H 191	5	165.71	1.18	0.36
				Error	18	506.92		
			2	H 191	5	956.28	2.76	0.05
				Error	18	1248.22		
			3	H 191	5	2754.34	4.77	0.01
				Error	18	2078.62		
			4	H 191	5	1390.74	3.19	0.03
				Error	18	1569.22		
			5	H 191	5	535.04	2.75	0.05
				Error	18	699.92		
			6	H 191	5	197.84	0.62	0.68
				Error	18	1145.12		
			7	H 191	5	91.38	0.45	0.81
				Error	18	725.95		
			8	H 191	5	132.88	0.75	0.60
				Error	18	635.62		
4	0 - 0.5	Lab	1	H 191	5	204.71	1.83	0.16
			1	Error	18	403.25		
			2	H 191	5	631.50	5.94	0.00
			2	Error	18	383.00		
			3	H 191	5	775.00	5.25	0.00
			3	Error	18	531.50		
			4	H 191	5	719.50	4.77	0.01
			4	Error	18	543.00		
			7	H 191	5	105.21	1.51	0.24
			7	Error	18	250.75		
			8	H 191	5	106.71	2.49	0.07
			8	Error	18	154.25		
3	0 - 10.0	Lab	1	H 191	5	506.38	2.22	0.10
				Error	18	821.62		
			2	H 191	5	3335.97	38.82	0.00
				Error	18	309.37		
			3	H 191	5	2708.88	11.68	0.00
				Error	18	835.12		
			4	H 191	5	3927.49	11.14	0.00
				Error	18	1269.47		
			5	H 191	5	766.34	5.13	0.00
				Error	18	537.62		
			6	H 191	5	435.22	2.88	0.04
				Error	18	544.12		
			7	H 191	5	168.71	1.11	0.39
				Error	18	545.92		
			8	H 191	5	76.87	0.39	0.85
				Error	18	706.97		

Table 5. Analysis of variance results for dry weight for field-collected algae (primarily *Hydrodictyon*) exposed to various concentration of Hydrothol 191 (algaecide). The concentrations, "0 to 0.5 PPM" = 0, 0.05, 0.1, 0.2, 0.3, 0.5 PPM; "0 to 5" = 0, 1, 2, 3, 4, 5 PPM; and "0 to 10" = 0, 6, 7, 8, 9, 10 PPM (PPM = parts per million). The experiments were conducted outdoors at the EIWRU facility in Davis, California.

Experiment	Hydrothol 191 Range (PPM)	Location	Source	DF	SS	F-value	Prob.
1	0 to 0.5	Davis	H191	5	0.25	1.10	0.39
			Error	18	0.81		
2	0 to 5.0	Davis	H191	5	0.37	1.72	0.18
			Error	18	0.78		
3	0 to 10.0	Davis	H191	5	1.05	2.47	0.07
			Error	18	1.52		
4	0 to 0.5	Davis	H191	5	0.16	3.23	0.03
			Error	18	0.18		
5	0 to 5.0	Davis	H191	5	0.51	12.64	0.00
			Error	18	0.14		
6	0 to 10.0	Davis	H191	5	1.30	15.51	0.00
			Error	18	0.30		

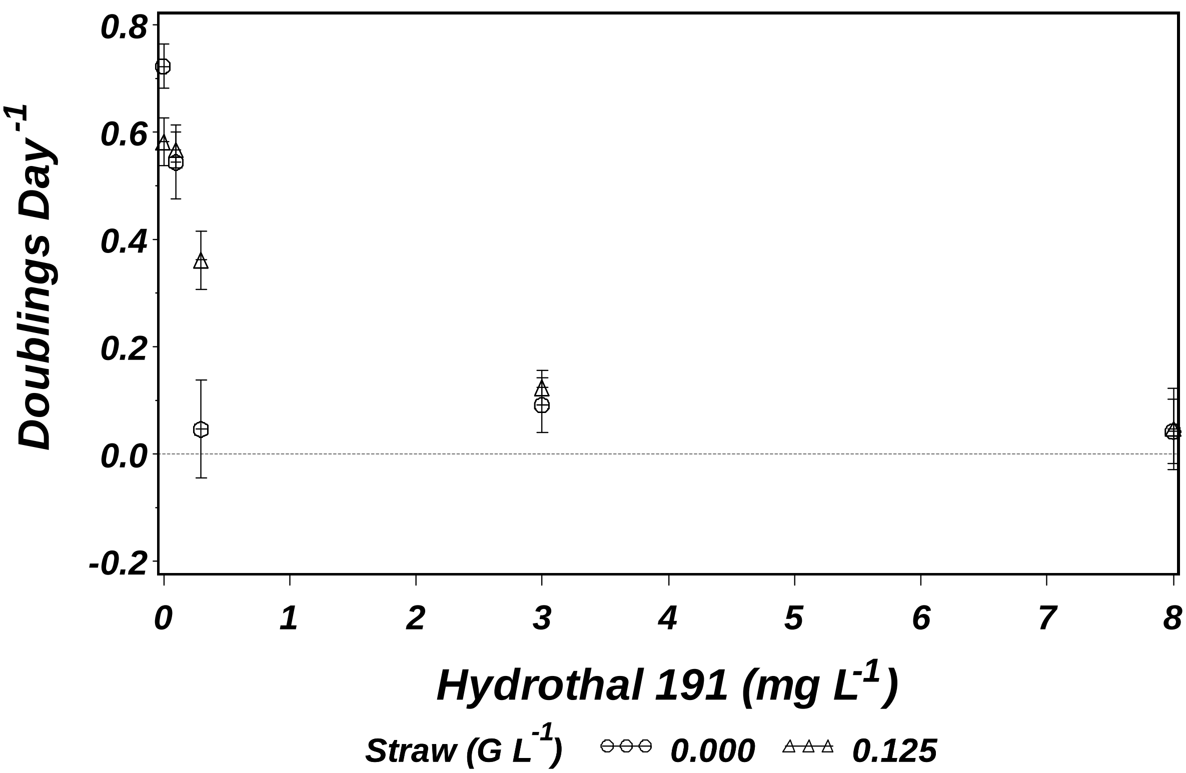


Figure 8. Effect of Hydrothol 191 algaecide on *Nostoc spongiaeforme* in laboratory cultures with 0.125 g rice straw. Plotted values are the mean ± 1 SE and based on four replications.

Table 6. Results of two-way analysis of variance for *Nostoc spongiaeforme* growth rates versus Hydrothol 191 (H191) and rice straw (0.125 g L^{-1}). Hydrothol 191 concentrations were: 0, 0.1, 0.3, 3, and 8 mg L^{-1} (ppm, parts per million).

Experiment	Source	DF	SS	F-value	Prob.
2	H 191	4	2.40	44.62	< 0.0001
	Straw	1	0.0220	1.64	0.21
	Straw x H 191	4	0.220	4.10	0.009
	Error	30	0.403		

Objective 2: Determine the effectiveness of four phosphorus fertilizer application methods for reducing algal growth.

We selected several checks from rice fields farmed by four growers located north and west of Gridley, California. In consultation with growers, checks were assigned to one of the following treatments: conventional, i.e., surface applied followed by a roller or 30 day delay, i.e., P fertilizer applied aerially 30 days after sowing. The amounts of P-fertilizer applied were approximately 41 kg ha^{-1} (46 lb $acre^{-1}$) as P_2O_5. The fields were prepared as indicated and flooded during the week of May 19, 2009. Shortly thereafter, we began to sample the fields for PO_4-P and algal abundance as described above.

Shortly after the growing season began, two growers treated their checks with copper sulfate to reduce algal growth. This prevented inclusion of data on algal/cyanobacteria abundance from these checks after the treatment, although we continued to collect water samples of PO_4-P determinations. Due to limited supplies of water, a third set of checks was partially dry for most of the thirty days following seeding. It was impossible to collect meaningful data on algal abundance or PO_4-P levels from these checks after our initial sampling. The results of these events is that only one set of checks (2 per treatment) provided complete data on both algae and PO_4-P levels for the entire sampling period. However, the data collected prior to copper sulfate application or field drying is included even though it does not cover the entire period of the study.

PO_4-P concentrations in water samples

In four of five experimental sites, PO_4-P concentrations in water samples collected from fields which received the delayed P fertilizer application were lower than in fields which received the conventional P-fertilizer application (Figures 9 and 10, Appendix 1). The difference between the two application methods ranged from 16% to 66% decrease in the fields that received the delayed P-fertilizer application (Table 7). In one case, FJK, water PO_4-P concentrations in the delayed application field were somewhat greater than for the conventionally applied field. Water PO_4-P concentrations increased dramatically following an aerial application of P-fertilizer at the end of the delay period. For most fields this was about 30 days after sowing, but for the 4SQ field it was 19 days after sowing.

Algal/cyanobacterial abundance

In three of five sites algal abundance was lower for the delayed P fertilizer checks and was about one-half of that for the conventional P-fertilizer treated checks.

More specifically for the STM site, algal abundance was significantly lower ($P < 0.0001$, Chi-square test) for the checks which received the delayed P fertilizer treatment (Figure 11). This was so even though the checks which received the delayed treatment were physically located between the two checks that received the conventional P fertilizer treatment (Figure 11). This meant that water flowed from the conventionally treated fields into the delayed treatment fields.

For the site designated 4Q2, the abundance of floating algal mats for the delayed P fertilizer checks was about one-half of that for the conventional P-fertilizer treated checks (Figure 12). The similarity between algal abundances following the application of the delayed P fertilizer (Figure 12) indicates the rapidity of algal growth under the prevailing water and light conditions in these checks (see below).

For the site designated NGT, the distribution of algae in the checks and the abundance of algae for each check are shown in Figure 13. Algal abundance was greater in the delayed P fields than in the conventionally treated fields (Figure 13). However, these data are only for the first sampling date (May 20, 2009). Shortly after they were collected an application of copper sulfate was made.

For site SHP, algal abundance was slightly higher in the conventionally treated field (Figure 14). Once again, however, these data are only for the first sampling date (May 22, 2009) as a copper sulfate application for algae control was made shortly after these data were collected.

For the two checks in the site designated FJK, the distribution of algae in the checks and the abundance of algae for each check are shown in Figure 15. Interestingly the abundance of algae in the conventional P fertilizer field was about four times that of algae in the 30 day delay P fertilizer field. These data are only for the first sampling date (May 20, 2009). Shortly after they were collected an application of copper sulfate was made.

Water PO_4-P levels in field C58 are included because this field had a delayed P fertilizer application made to it. The dynamics of water PO_4-P levels in this field are interesting even though there was not a control field to compare it to. In this field the initial PO_4-P reading was quite high (the source water for this field had 1.56 mg L^{-1} PO_4-P; see Appendix 1) however water PO_4-P concentrations declined within 7 days and remained relatively low until the sample collected just after the delayed P fertilizer was applied. This decline may be due to a combination of P uptake by algae and other plants growing in this rice field. The increase in PO_4-P water levels after application of the delayed P fertilizer is consistent with that observed in other fields.

Table 7. Mean PO_4-P concentrations in water from rice checks receiving one of two P fertilizer application methods, i.e., conventional (liquid P-fertilizer followed by a roller, prior to flooding) or application of P-fertilizer 30 days after sowing (30 Day). Values are the mean of 6 or 8 samples per check on each sampling date. In the case of the 4SQ field there were two checks per method for a total of 16 samples. The table includes the difference (%) between the two methods. Negative values indicate how much of a decrease in PO_4-P level there was between the two methods. Fields 4Q2, FJK, NGT, and C58 were all sampled after the application of the delayed P-fertilizer (approximately 41 kg ha^{-1} (46 lb $acre^{-1}$) as P_2O_5). This accounts for the increased PO_4-P readings on the last sample dates.

Field	Date	PO_4-P MG L^{-1} 30 Day	PO_4-P MG L^{-1} Conventional	% Difference
4Q2	20MAY2009	0.036	0.084	-57
	02JUN2009	0.086	0.134	-36
	09JUN2009	0.565	0.067	0
FJK	20MAY2009	0.046	0.054	-16
	02JUN2009	0.126	0.096	+23
	17JUN2009	0.444	0.030	+1480
NGT	18MAY2009	0.040	0.066	-40
	17JUN2009	1.368	0.079	+1731
SHP	22MAY2009	0.033	0.075	-56
	05JUN2009	0.063	0.123	-49
STM	26MAY2009	0.030	0.090	-66
	17JUN2009	0.054	0.079	-31
C58	04MAY2009	0.365	--	--
	11MAY2009	0.038	--	--
	18MAY2009	0.083	--	--
	02JUN2009	1.653	--	--

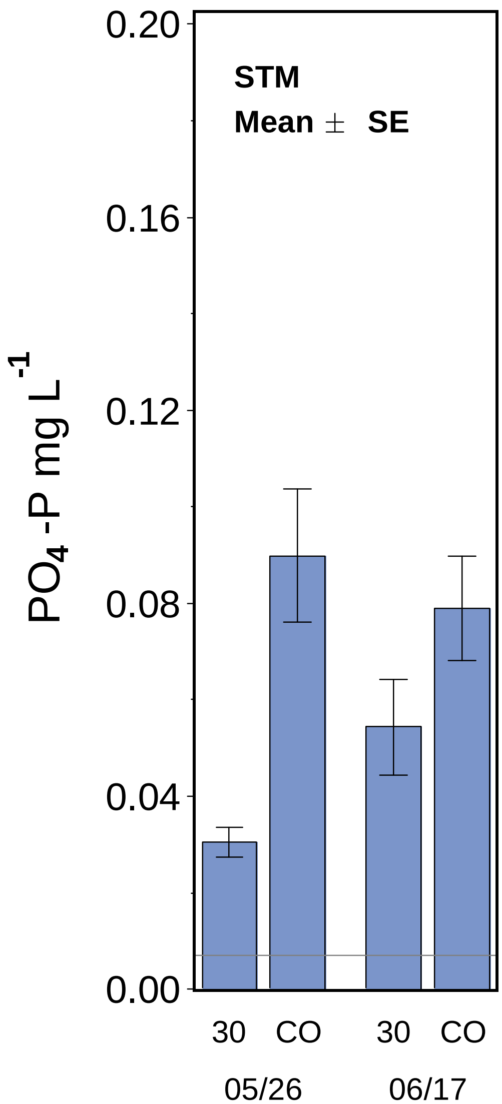


Figure 9. PO_4-P concentration in water samples from field STM. Values are based on 16 water samples collected from each treatment (8 samples from each of 2 checks) on each date. The horizontal line represents the PO_4-P concentration of the source water.

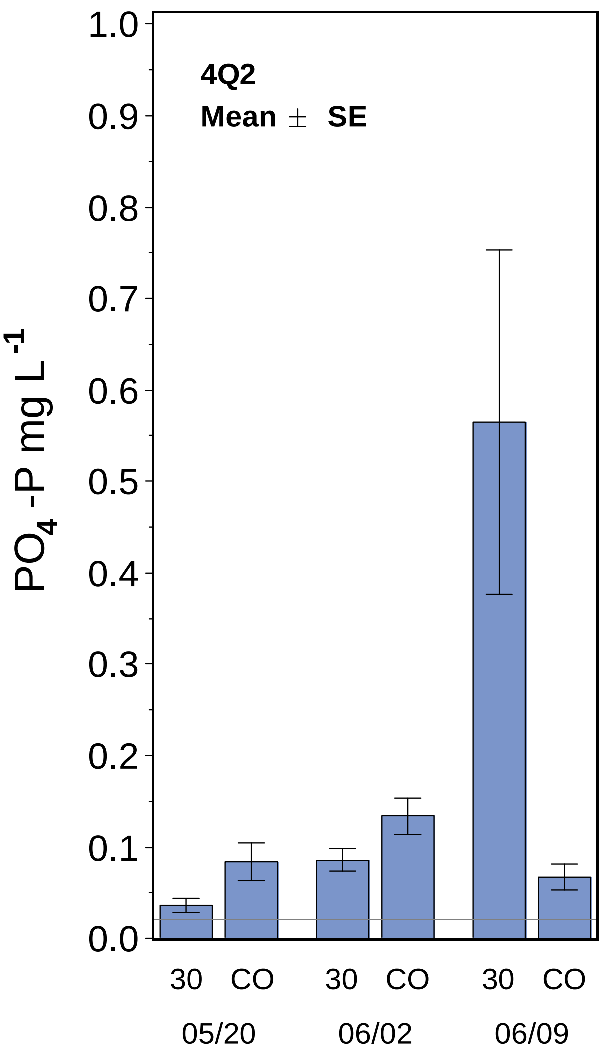


Figure 10. PO_4-P concentration in water samples from field 4Q2. Values are based on 16 water samples collected from each treatment (8 samples from each of 2 checks) on each date. The horizontal line represents the PO_4-P concentration of the source water. An aerial application of P was made on June 4, 2009 which is 16 days after initial flooding of the field. P applications were approximately 41 kg ha^{-1} (46 lb $acre^{-1}$) as P_2O_5.

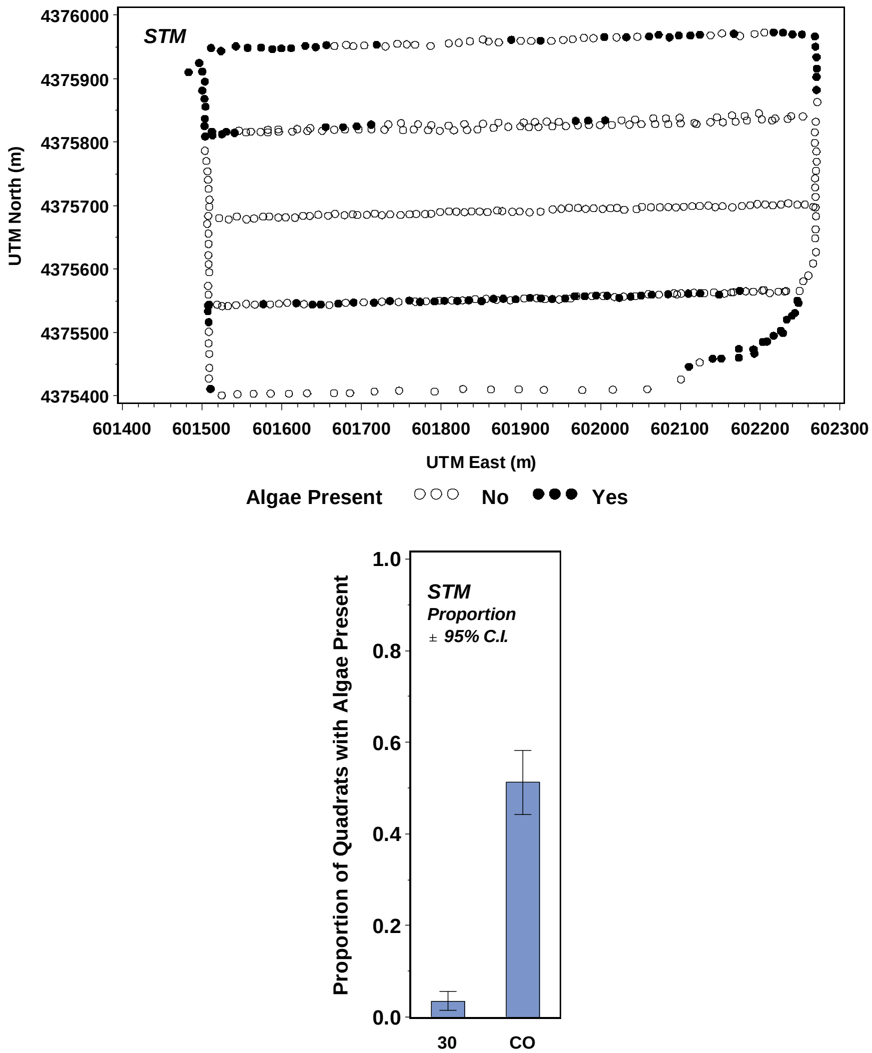


Figure 11. Upper panel is a map of locations within each check where algae were present (indicated by Yes = solid dot) for field STM. Lower panel shows the proportion of quadrats (i.e., photographs) with algae present in field STM for each P application type. "30" indicates that the P was applied after 30 days and "CO" indicates P was applied as a liquid to the surface followed by a roller just prior to flooding of the field. Values are statistically different for each date ($P < 0.0001$), based on Chi-square calculated by the frequency procedure in SAS (2004).

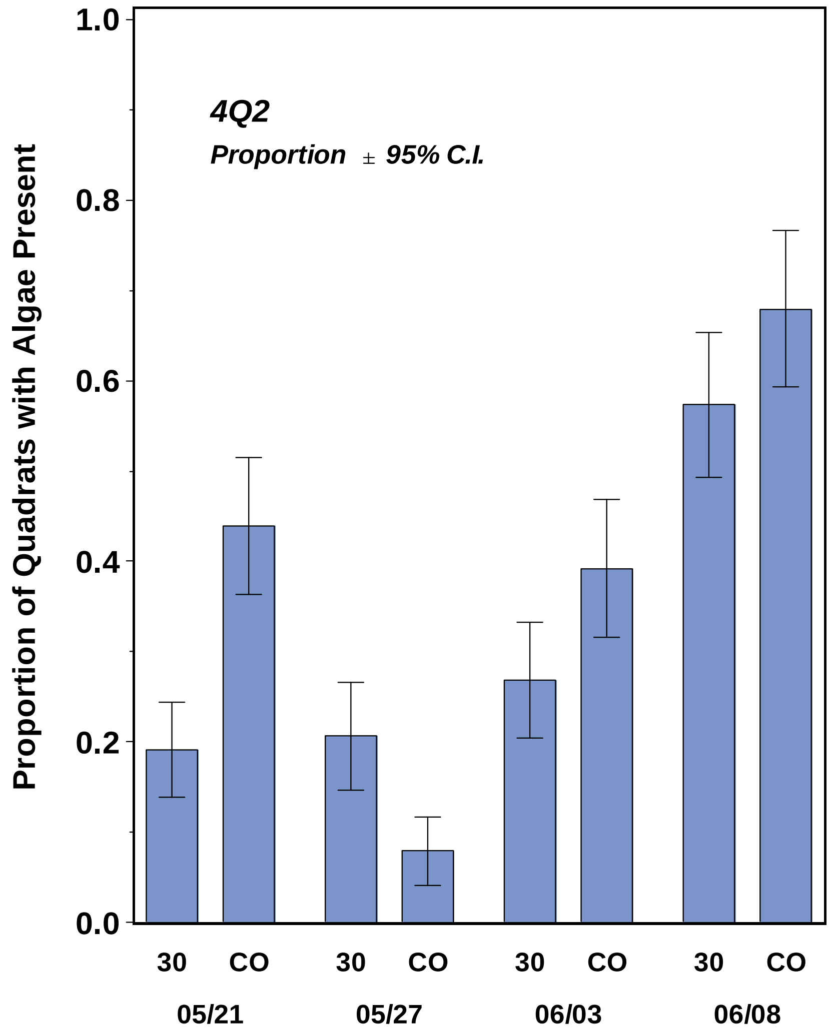
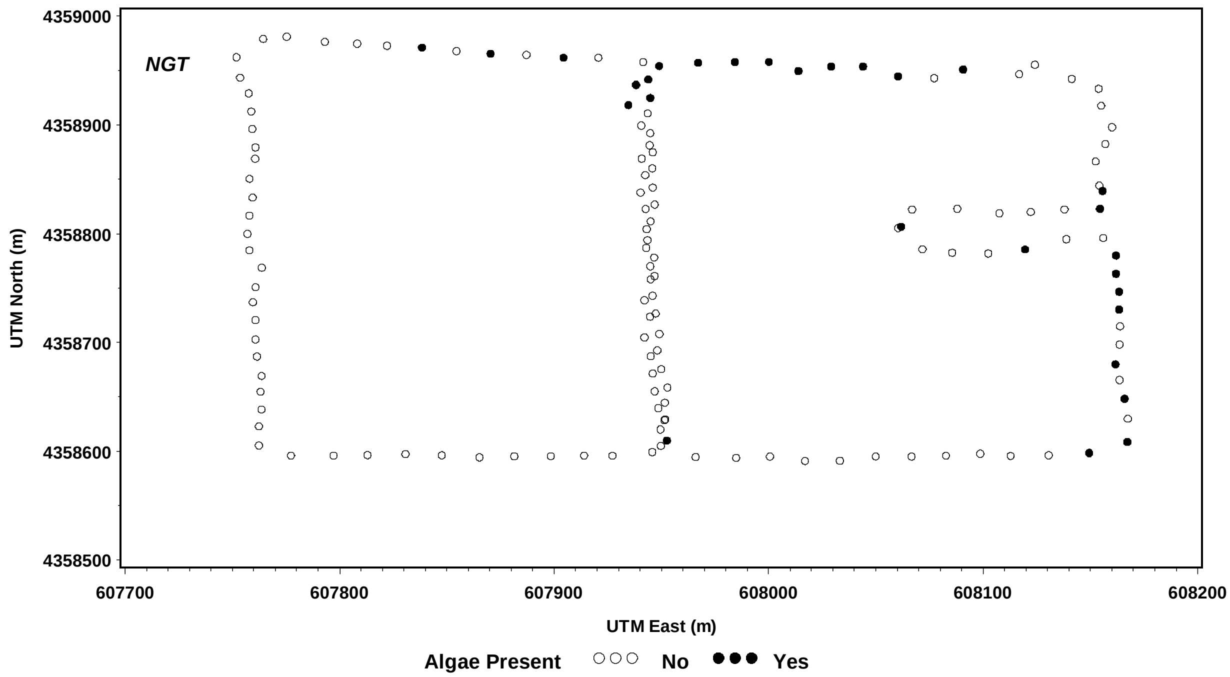


Figure 12. Proportion of quadrats (i.e., photographs) with algae present in field 4Q2. Values are statistically different for each date ($P < 0.0001$; $P=0.0002$; $P = 0.02$) except the last ($P=0.07$), based on Chi-square calculated by the frequency procedure in SAS (2004). For 5/21, N=352; for 5/27, N = 294, for 6/3, N = 321; and for 6/8, N = 285. An aerial application of P was made on June 4, 2009 which is 16 days after initial flooding of the field. P applications were approximately 41 kg ha^{-1} (46 lb $acre^{-1}$) as P_2O_5.



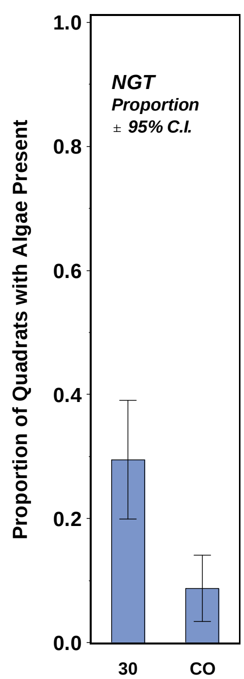
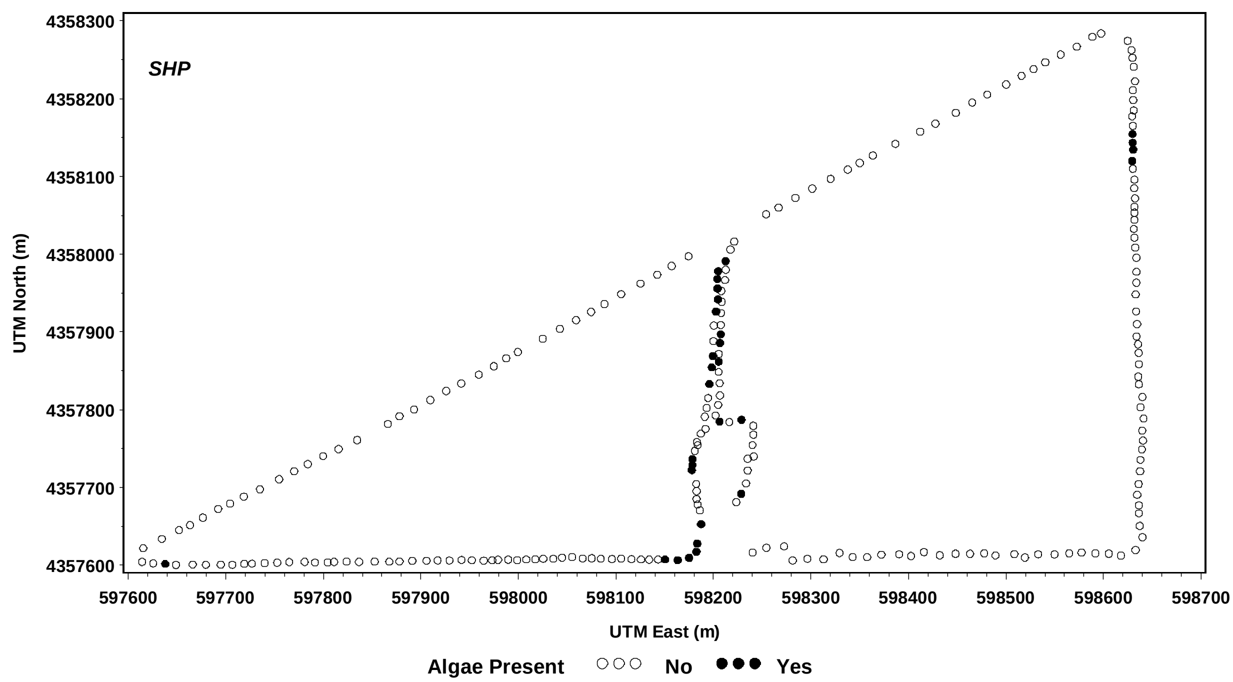


Figure 13. Upper panel is a map of locations within each check where algae were present (indicated by Yes = solid dot) for field NGT, on May 20, 2009. Lower panel shows the proportion of quadrats (i.e., photographs) with algae present in field STM for each P application type. “30” indicates that the P was applied after 30 days and “CO” indicates P was applied as a liquid to the surface followed by a roller just prior to flooding of the field. Values are statistically different for each date ($P < 0.0001$), based on Chi-square calculated by the frequency procedure in SAS (2004).



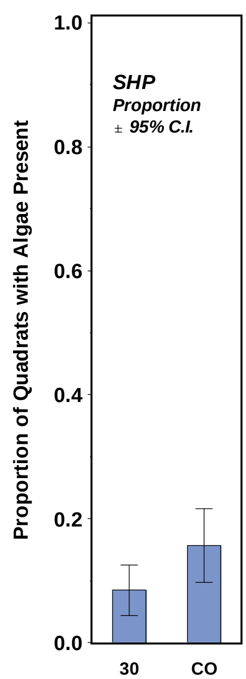


Figure 14. Upper panel is a map of locations within each check where algae were present (indicated by Yes = solid dot) for field SHP, on May 22, 2009. Lower panel shows the proportion of quadrats (i.e., photographs) with algae present in field STM for each P application type. "30" indicates that the P was applied after 30 days and "CO" indicates P was applied as a liquid to the surface followed by a roller just prior to flooding of the field. Values are not statistically different (P = 0.08), based on Chi-square calculated by the frequency procedure in SAS (2004).

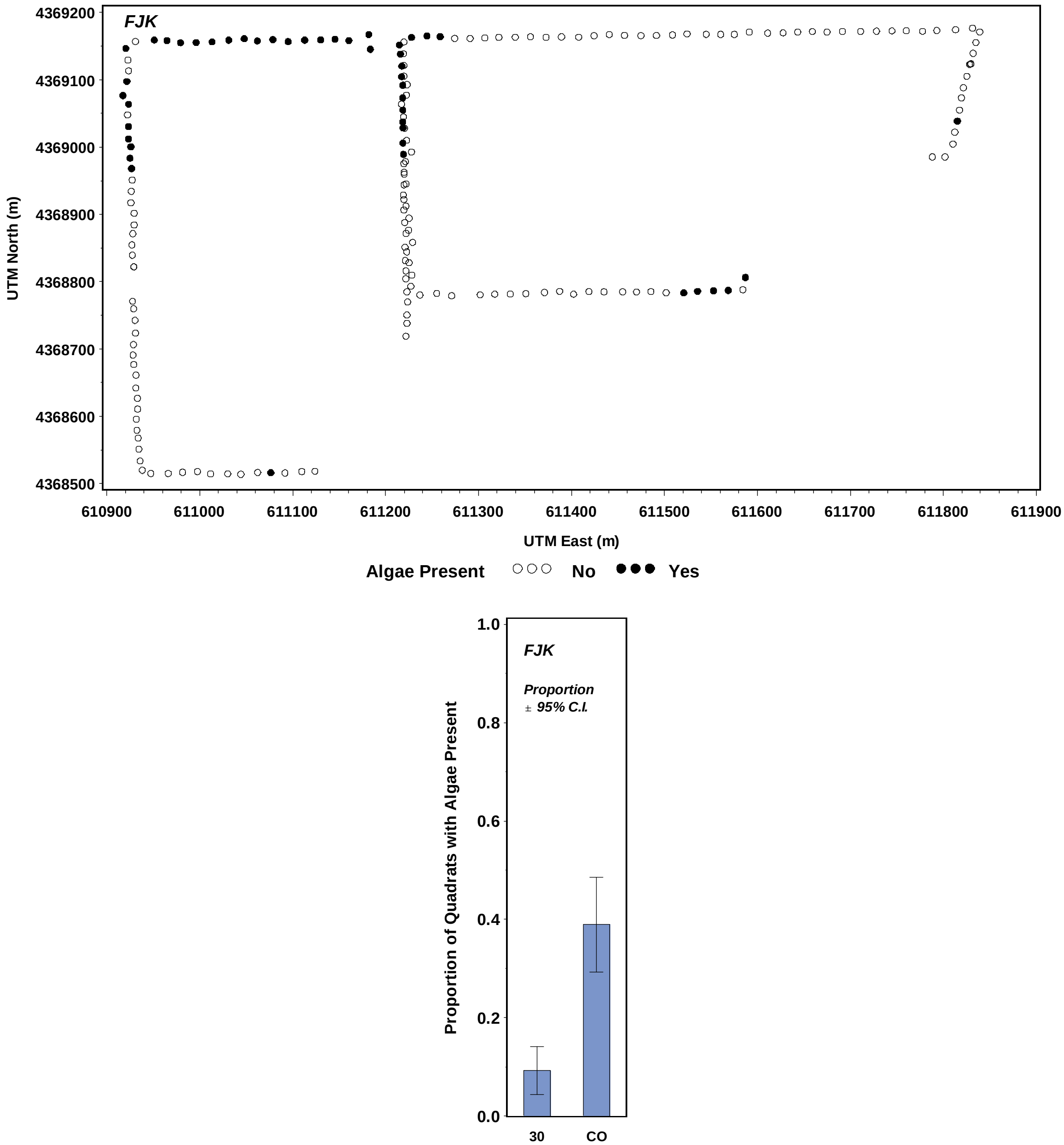


Figure 15. Upper panel is a map of locations within each check where algae were present (indicated by Yes = solid dot) for field FJK, on May 20, 2009. Lower panel shows the proportion of quadrats (i.e., photographs) with algae present in field FJK for each P application type. “30” indicates that the P was applied after 30 days and “CO” indicates P was applied as a liquid to the surface followed by a roller just prior to flooding of the field. Values are statistically different ($P < 0.0001$), based on Chi-square calculated by the frequency procedure in SAS (2004).

The Rice Field Environment

Figures 16, 17, 18 show the diurnal changes in water temperature for several rice fields that were flooded for the entire period. Examination of these data shows that minimum and maximum daily water temperature fluctuated more, during the initial period following sowing. This may be due to increased water additions during this period or due to the fact that once rice plants form a canopy the resulting shading buffers water temperatures or to a combination of these effects. The water temperatures at the soil surface collected during 2009 indicate that the temperatures in the bucket and laboratory studies were ecologically reasonable (see Appendix 2).

On June 15, 17, 19, and June 22, 2009 we collected a total of 88 samples of *N. spongiaeforme* to determine biomass. A subset of 31 samples were sub-sampled and analyzed for tissue P concentration. The mean tissue P concentration for *N. spongiaeforme* was 0.264 % with a standard deviation of 0.126 %. This information may also be useful for constructing a realistic growth model for *N. spongiaeforme* in rice fields. The 88 biomass samples varied from 0.079 g m^{-2} to 67.4 g m^{-2} dry weight. The mean biomass was 12.97 g m^{-2} with a standard deviation of 13.6 g m^{-2} and 95% confidence limits of 10.10 to 15.85 g m^{-2}. The standing crop of P was estimated as 0.034 g m^{-2} P by multiplying the mean biomass by the mean tissue P concentration. The standard deviation was 0.035 g m^{-2} P and the 95% confidence limits were 0.027 to 0.042 g m^{-2} P.

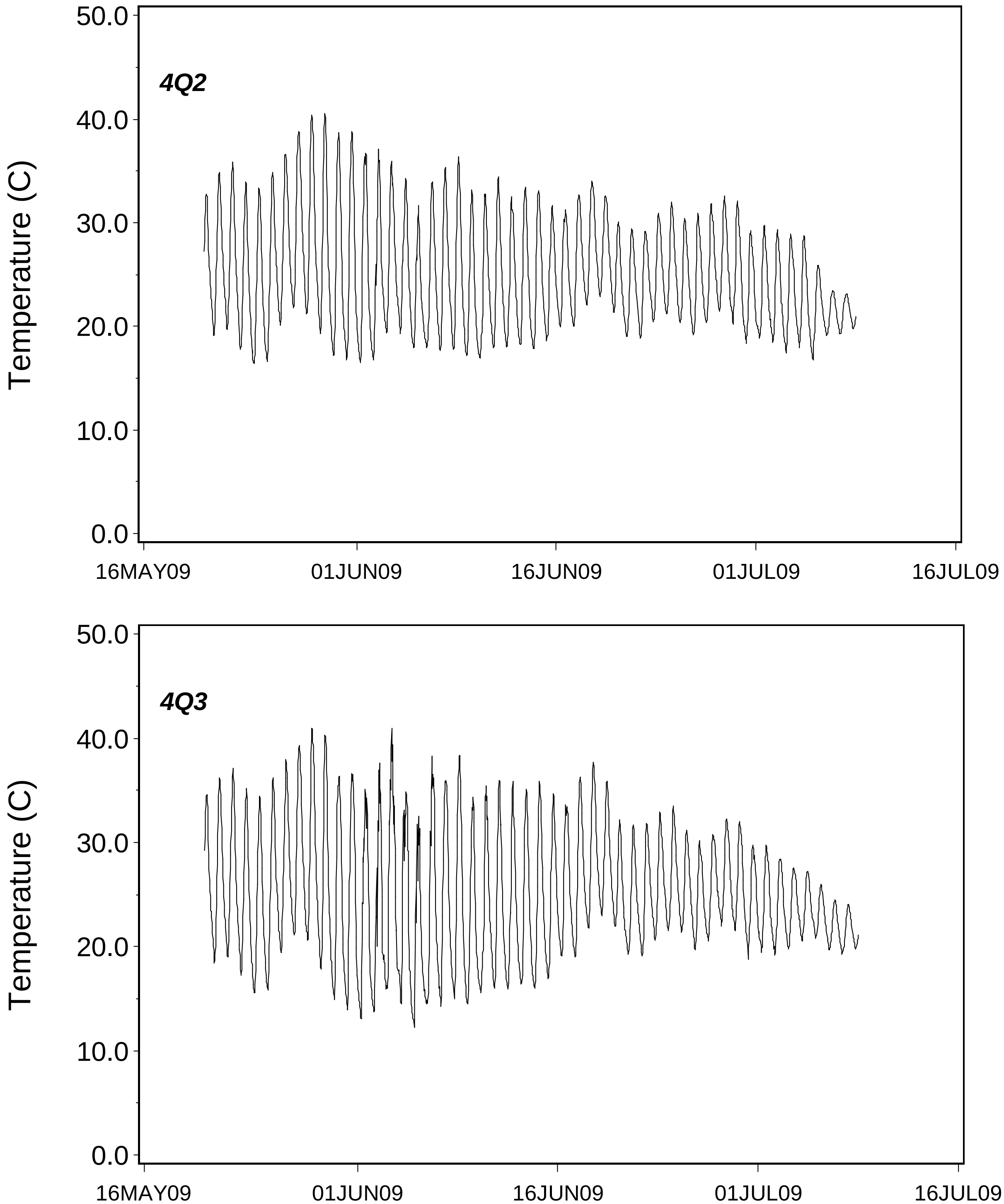


Figure 16. Daily temperature (C) variations in two northern California rice checks. Measurements were collected at 0.5 h intervals.

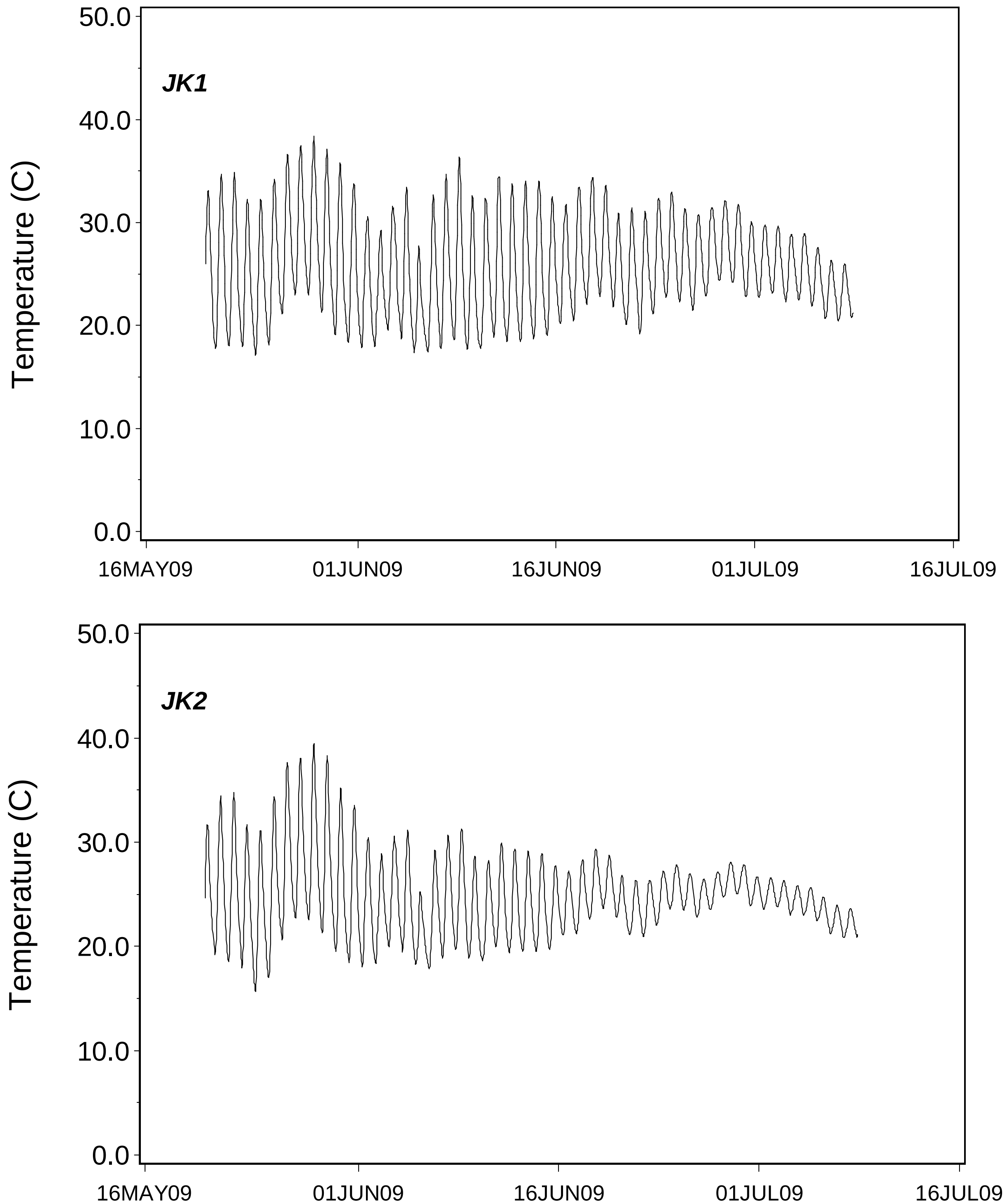


Figure 17. Daily temperature (C) variations in two northern California rice checks. Measurements were collected at 0.5 h intervals.

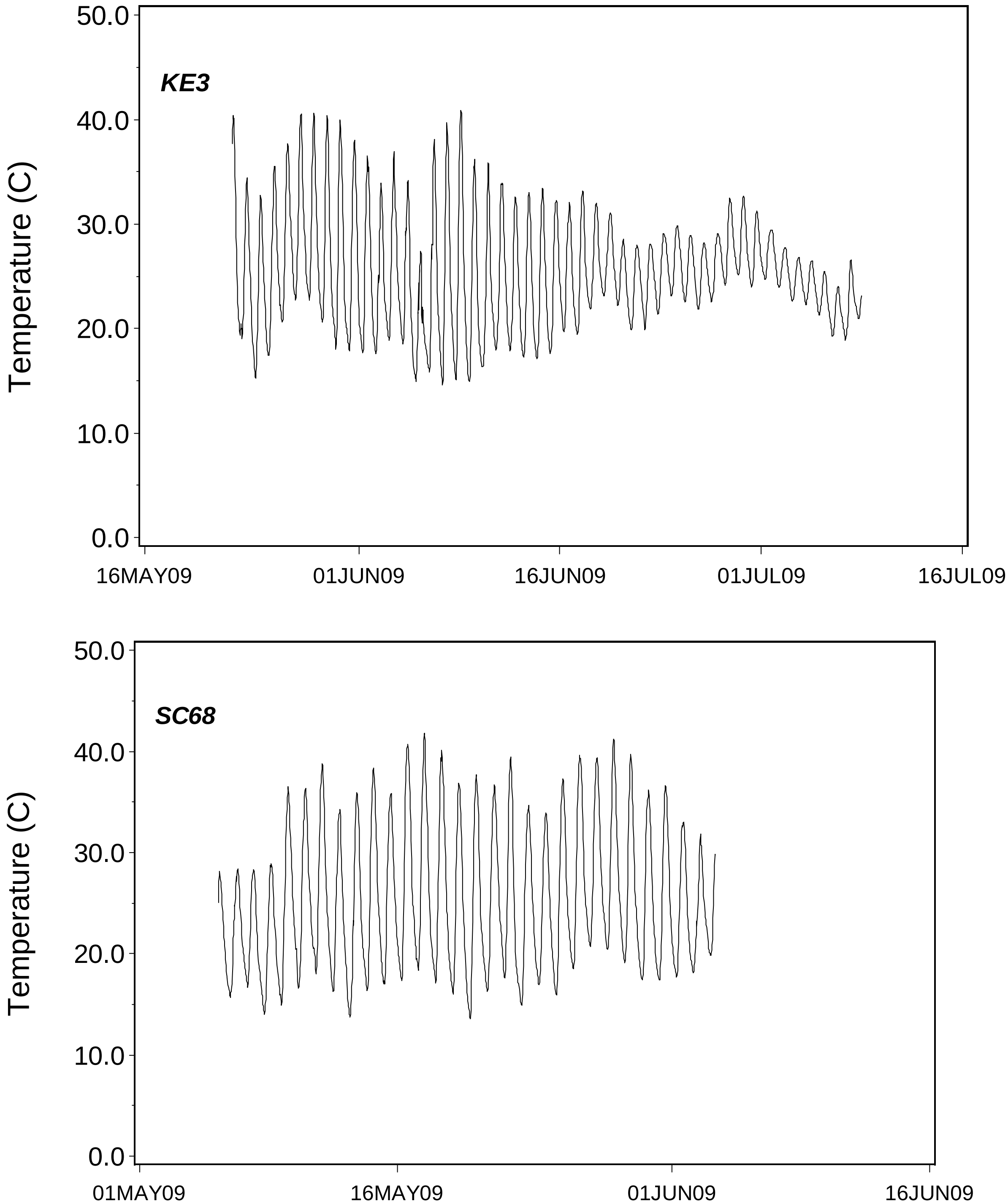


Figure 18. Daily temperature (C) variations in two northern California rice checks. Measurements were collected at 0.5 h intervals.

PUBLICATIONS OR REPORTS:

- D. F. Spencer, P. S. Liow, C. A. Lembi, 2009. Effect of a combination of two rice herbicides, Londax and Shark, on the cyanobacterium, *Nostoc spongiaeforme*. *Journal of Aquatic Plant Management* 47: (in press).

- Oral report, Effective methods used for the control of *Nostoc* in rice fields, March 5, 2009, Big Valley Ag Services PCA Meeting, Gridley, California.

- Oral report, Research update on controlling rice algae problem, *Nostoc*, November 3, 2009, Sutter Buttes CAPCA Annual Rice Meeting, Colusa, California.

- Oral Report at California Rice Research Board Meeting, December 1, 2009, Davis, California.

CONCISE GENERAL SUMMARY OF CURRENT YEAR'S RESULTS:

We conducted 12 field experiments covering a range of Hydrothol 191 concentrations from 0 to 10 parts per million to test its effect on *Nostoc*, "black algae." (The highest concentration listed for use on the Hydrothol 191 label is 5 parts per million). Hydrothol 191 did not have a detrimental effect on *Nostoc* until the concentration exceeded 6 ppm. The effect was noticeable after 2 or 3 days exposure at these concentrations. At lower Hydrothol 191 concentrations, *Nostoc* recovered from the effects of Hydrothol 191 by the end of the 7 day exposure period.

We also conducted 6 experiments using the green algae, water net (*Hydrodictyon*), collected from a rice field where we have previously observed it to grow and cause a considerable problem to the grower. Water net showed a similar decrease upon exposure to Hydrothol 191. This was especially clear at Hydrothol 191 concentrations above 5 parts per million. Water net chlorophyll content also recovered by the end of the experiments, but dry weight was reduced at higher levels of Hydrothol 191.

In laboratory experiments, Hydrothol 191 was quite toxic to *Nostoc*. But when rice straw was added to the growth medium, the toxicity of Hydrothol 191 was reduced. It may be that rice straw and Hydrothol 191 interact to render Hydrothol 191 in a form that is non-toxic to *Nostoc*. It is also possible that the introduction of rice straw has also introduced bacteria or promoted the growth of bacteria that can breakdown Hydrothol 191. Either of these mechanisms could partially explain the temporary (3 to 5 days) reduction in chlorophyll reflectance measured in the bucket experiments.

The results of these outdoor and laboratory experiments indicate that Hydrothol 191 did not consistently kill *Nostoc* (black algae) even at concentrations greater than the maximum permissible rate, 5 parts per million. Its effect on the green algae, water net, was more pronounced and lasting. It appears that water quality including the abundance of bacteria may impact the effect of Hydrothol 191 on rice algae. At present this algaecide is not labeled for use in California rice fields and it is not clear how it may fit into algal control strategies for them.

Results from field studies comparing two phosphorus fertilizer application methods (P fertilizer applied 19 to 30 days after flooding, or surface applied liquid phosphate fertilizer followed by a roller) indicate that phosphate water concentrations were lower in fields where P fertilizer application was delayed either 19 or 30 days after sowing. In most cases, algal abundance was also lowest for fields which received the delayed P fertilizer treatment. These fields had less "algae" than fields which received the conventional phosphate application, i.e., surface application of a liquid phosphate fertilizer followed by a roller. The results of these measurements clearly show that phosphate water concentrations and algal abundance were reduced by the delayed P fertilizer application method. Delaying P fertilizer application until rice seedlings have emerged from the water may be an alternative "algae" management method for some growers.

Appendix 1

The following pages contain the data on PO_4-P levels in water samples collected from various rice fields in 2009. The column labeled "Type" indicates whether the sample was collected from within the check (i.e., field) or if it represents a sample from a check "inlet" or "outlet." Inlets and outlets may just connect one check to another and whether it was an inlet or outlet depending on the direction that the water was moving at the time the sample was collected. The type "source" indicates the sample was collected from the source of water entering the check or field. In general the samples were collected from each side of the check. If the check was triangular then six samples were collected, while rectangular checks would have had eight samples collected from them. The names of the fields and locations of the samples have been coded to protect privacy. Some data included in this appendix are from fields not necessarily in the study from the beginning. However, they have been included in this appendix to enhance data on rice field PO_4-P levels which is limited in abundance.

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
4Q2	20MAY2009	30daypost	1	FIELD	0.021
4Q2	20MAY2009	30daypost	1	FIELD	0.172
4Q2	20MAY2009	30daypost	1	FIELD	0.038
4Q2	20MAY2009	30daypost	1	FIELD	0.021
4Q2	20MAY2009	30daypost	1	FIELD	0.016
4Q2	20MAY2009	30daypost	1	FIELD	0.016
4Q2	20MAY2009	30daypost	1	FIELD	0.021
4Q2	20MAY2009	30daypost	1	INLET	0.023
4Q2	20MAY2009	30daypost	1	SOURCE	0.021
4Q2	20MAY2009	30daypost	2	FIELD	0.021
4Q2	20MAY2009	30daypost	2	FIELD	0.034
4Q2	20MAY2009	30daypost	2	FIELD	0.029
4Q2	20MAY2009	30daypost	2	FIELD	0.029
4Q2	20MAY2009	30daypost	2	FIELD	0.025
4Q2	20MAY2009	30daypost	2	FIELD	0.046
4Q2	20MAY2009	30daypost	2	FIELD	0.055
4Q2	20MAY2009	30daypost	2	OUTLET	0.025
4Q2	20MAY2009	conventional	3	FIELD	0.072
4Q2	20MAY2009	conventional	3	FIELD	0.070
4Q2	20MAY2009	conventional	3	FIELD	0.016
4Q2	20MAY2009	conventional	3	FIELD	0.106
4Q2	20MAY2009	conventional	3	FIELD	0.076
4Q2	20MAY2009	conventional	3	FIELD	0.095
4Q2	20MAY2009	conventional	3	FIELD	0.061
4Q2	20MAY2009	conventional	3	FIELD	0.081
4Q2	20MAY2009	conventional	4	FIELD	0.083
4Q2	20MAY2009	conventional	4	FIELD	0.040
4Q2	20MAY2009	conventional	4	FIELD	0.049
4Q2	20MAY2009	conventional	4	FIELD	0.430
4Q2	20MAY2009	conventional	4	FIELD	0.042
4Q2	20MAY2009	conventional	4	FIELD	0.038
4Q2	20MAY2009	conventional	4	FIELD	0.057
4Q2	20MAY2009	conventional	4	INLET	0.029
4Q2	02JUN2009	30daypost	1	FIELD	0.115
4Q2	02JUN2009	30daypost	1	FIELD	0.040
4Q2	02JUN2009	30daypost	1	FIELD	0.087
4Q2	02JUN2009	30daypost	1	FIELD	0.034
4Q2	02JUN2009	30daypost	1	FIELD	0.063
4Q2	02JUN2009	30daypost	1	FIELD	0.132
4Q2	02JUN2009	30daypost	1	INLET	0.019
4Q2	02JUN2009	30daypost	1	OUTLET	0.016
4Q2	02JUN2009	30daypost	2	FIELD	0.051

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
4Q2	02JUN2009	30daypost	2	FIELD	0.145
4Q2	02JUN2009	30daypost	2	FIELD	0.211
4Q2	02JUN2009	30daypost	2	FIELD	0.076
4Q2	02JUN2009	30daypost	2	FIELD	0.108
4Q2	02JUN2009	30daypost	2	FIELD	0.078
4Q2	02JUN2009	30daypost	2	FIELD	0.140
4Q2	02JUN2009	30daypost	2	INLET	0.057
4Q2	02JUN2009	conventional	3	FIELD	0.183
4Q2	02JUN2009	conventional	3	FIELD	0.108
4Q2	02JUN2009	conventional	3	FIELD	0.147
4Q2	02JUN2009	conventional	3	FIELD	0.157
4Q2	02JUN2009	conventional	3	FIELD	0.061
4Q2	02JUN2009	conventional	3	FIELD	0.145
4Q2	02JUN2009	conventional	3	FIELD	0.106
4Q2	02JUN2009	conventional	3	FIELD	0.083
4Q2	02JUN2009	conventional	4	FIELD	0.253
4Q2	02JUN2009	conventional	4	FIELD	0.025
4Q2	02JUN2009	conventional	4	FIELD	0.076
4Q2	02JUN2009	conventional	4	FIELD	0.115
4Q2	02JUN2009	conventional	4	FIELD	0.379
4Q2	02JUN2009	conventional	4	FIELD	0.119
4Q2	02JUN2009	conventional	4	FIELD	0.179
4Q2	02JUN2009	conventional	4	INLET	0.008
4Q2	09JUN2009	30daypost	1	FIELD	0.173
4Q2	09JUN2009	30daypost	1	FIELD	0.089
4Q2	09JUN2009	30daypost	1	FIELD	0.207
4Q2	09JUN2009	30daypost	1	FIELD	0.543
4Q2	09JUN2009	30daypost	2	FIELD	0.153
4Q2	09JUN2009	30daypost	2	FIELD	1.814
4Q2	09JUN2009	30daypost	2	FIELD	0.638
4Q2	09JUN2009	30daypost	2	FIELD	0.905
4Q2	09JUN2009	conventional	3	FIELD	0.028
4Q2	09JUN2009	conventional	3	FIELD	0.155
4Q2	09JUN2009	conventional	3	FIELD	0.048
4Q2	09JUN2009	conventional	3	FIELD	0.024
4Q2	09JUN2009	conventional	4	FIELD	0.069
4Q2	09JUN2009	conventional	4	FIELD	0.104
4Q2	09JUN2009	conventional	4	FIELD	0.043
4Q2	09JUN2009	conventional	4	FIELD	0.067
C58	04MAY2009	30daypost	1	FIELD	0.458
C58	04MAY2009	30daypost	1	FIELD	0.454
C58	04MAY2009	30daypost	1	FIELD	0.031

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
C58	04MAY2009	30daypost	1	FIELD	0.405
C58	04MAY2009	30daypost	1	FIELD	0.098
C58	04MAY2009	30daypost	1	FIELD	0.138
C58	04MAY2009	30daypost	1	FIELD	0.093
C58	04MAY2009	30daypost	1	FIELD	0.081
C58	04MAY2009	30daypost	1	INLET	0.396
C58	04MAY2009	30daypost	1	OUTLET	0.298
C58	04MAY2009	30daypost	1	SOURCE	1.559
C58	11MAY2009	30daypost	1	FIELD	0.066
C58	11MAY2009	30daypost	1	FIELD	0.089
C58	11MAY2009	30daypost	1	FIELD	0.040
C58	11MAY2009	30daypost	1	FIELD	0.016
C58	11MAY2009	30daypost	1	FIELD	0.029
C58	11MAY2009	30daypost	1	FIELD	0.023
C58	11MAY2009	30daypost	1	FIELD	0.027
C58	11MAY2009	30daypost	1	FIELD	0.014
C58	18MAY2009	30daypost	1	FIELD	0.010
C58	18MAY2009	30daypost	1	FIELD	0.012
C58	18MAY2009	30daypost	1	FIELD	0.008
C58	18MAY2009	30daypost	1	FIELD	0.051
C58	18MAY2009	30daypost	1	FIELD	0.599
C58	18MAY2009	30daypost	1	FIELD	0.023
C58	18MAY2009	30daypost	1	FIELD	0.012
C58	18MAY2009	30daypost	1	FIELD	0.025
C58	18MAY2009	30daypost	1	INLET	0.010
C58	02JUN2009	30daypost	1	FIELD	1.474
C58	02JUN2009	30daypost	1	FIELD	1.813
C58	02JUN2009	30daypost	1	FIELD	1.386
C58	02JUN2009	30daypost	1	FIELD	2.449
C58	02JUN2009	30daypost	1	FIELD	1.081
C58	02JUN2009	30daypost	1	FIELD	2.039
C58	02JUN2009	30daypost	1	INLET	1.647
C58	02JUN2009	30daypost	1	OUTLET	1.337
DCK	18JUN2009	30daypost	1	FIELD	0.153
DCK	18JUN2009	30daypost	1	FIELD	0.267
DCK	18JUN2009	30daypost	1	FIELD	0.991
DCK	18JUN2009	30daypost	1	FIELD	0.213
DCK	18JUN2009	30daypost	1	FIELD	0.267
DCK	18JUN2009	30daypost	1	FIELD	0.104
DCK	18JUN2009	30daypost	1	SOURCE	0.114
DCK	18JUN2009	30daypost	2	FIELD	0.026
DCK	18JUN2009	30daypost	2	FIELD	0.127
DCK	18JUN2009	30daypost	2	FIELD	0.132

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
DCK	18JUN2009	30daypost	2	FIELD	0.377
DCK	18JUN2009	30daypost	2	FIELD	0.235
DCK	18JUN2009	30daypost	2	FIELD	0.134
DCK	18JUN2009	conventional	1	FIELD	0.093
DCK	18JUN2009	conventional	1	FIELD	0.192
DCK	18JUN2009	conventional	1	FIELD	0.297
DCK	18JUN2009	conventional	1	FIELD	0.237
DCK	18JUN2009	conventional	1	FIELD	0.388
DCK	18JUN2009	conventional	1	FIELD	0.119
DCK	18JUN2009	conventional	1	SOURCE	0.114
FJK	20MAY2009	30daypost	1	FIELD	0.081
FJK	20MAY2009	30daypost	1	FIELD	0.061
FJK	20MAY2009	30daypost	1	FIELD	0.038
FJK	20MAY2009	30daypost	1	FIELD	0.025
FJK	20MAY2009	30daypost	1	FIELD	0.034
FJK	20MAY2009	30daypost	1	FIELD	0.029
FJK	20MAY2009	30daypost	1	FIELD	0.042
FJK	20MAY2009	30daypost	1	FIELD	0.061
FJK	20MAY2009	30daypost	1	FIELD	0.063
FJK	20MAY2009	30daypost	1	SOURCE	0.021
FJK	20MAY2009	conventional	2	FIELD	0.085
FJK	20MAY2009	conventional	2	FIELD	0.074
FJK	20MAY2009	conventional	2	FIELD	0.016
FJK	20MAY2009	conventional	2	FIELD	0.076
FJK	20MAY2009	conventional	2	FIELD	0.061
FJK	20MAY2009	conventional	2	FIELD	0.063
FJK	20MAY2009	conventional	2	FIELD	0.061
FJK	20MAY2009	conventional	2	FIELD	0.040
FJK	20MAY2009	conventional	2	INLET	0.014
FJK	02JUN2009	30daypost	1	FIELD	0.132
FJK	02JUN2009	30daypost	1	FIELD	0.042
FJK	02JUN2009	30daypost	1	FIELD	0.102
FJK	02JUN2009	30daypost	1	FIELD	0.100
FJK	02JUN2009	30daypost	1	FIELD	0.371
FJK	02JUN2009	30daypost	1	FIELD	0.044
FJK	02JUN2009	30daypost	1	FIELD	0.200
FJK	02JUN2009	30daypost	1	INLET	0.014
FJK	02JUN2009	conventional	2	FIELD	0.074
FJK	02JUN2009	conventional	2	FIELD	0.221
FJK	02JUN2009	conventional	2	FIELD	0.012
FJK	02JUN2009	conventional	2	FIELD	0.140
FJK	02JUN2009	conventional	2	FIELD	0.034
FJK	02JUN2009	conventional	2	FIELD	0.166

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
FJK	02JUN2009	conventional	2	FIELD	0.106
FJK	02JUN2009	conventional	2	INLET	0.016
FJK	17JUN2009	30daypost	1	FIELD	0.461
FJK	17JUN2009	30daypost	1	FIELD	0.181
FJK	17JUN2009	30daypost	1	FIELD	0.030
FJK	17JUN2009	30daypost	1	FIELD	0.028
FJK	17JUN2009	30daypost	1	FIELD	1.680
FJK	17JUN2009	30daypost	1	FIELD	1.041
FJK	17JUN2009	30daypost	1	FIELD	0.125
FJK	17JUN2009	30daypost	1	FIELD	0.009
FJK	17JUN2009	conventional	2	FIELD	0.024
FJK	17JUN2009	conventional	2	FIELD	0.039
FJK	17JUN2009	conventional	2	FIELD	0.011
FJK	17JUN2009	conventional	2	FIELD	0.009
FJK	17JUN2009	conventional	2	FIELD	0.024
FJK	17JUN2009	conventional	2	FIELD	0.037
FJK	17JUN2009	conventional	2	FIELD	0.084
FJK	17JUN2009	conventional	2	FIELD	0.009
KGT	18MAY2009	30daypost	1	FIELD	0.040
KGT	18MAY2009	30daypost	1	FIELD	0.025
KGT	18MAY2009	30daypost	1	FIELD	0.029
KGT	18MAY2009	30daypost	1	FIELD	0.038
KGT	18MAY2009	30daypost	1	FIELD	0.034
KGT	18MAY2009	30daypost	1	FIELD	0.034
KGT	18MAY2009	30daypost	1	FIELD	0.042
KGT	18MAY2009	30daypost	1	FIELD	0.031
KGT	18MAY2009	30daypost	1	SOURCE	0.083
KGT	18MAY2009	conventional	2	FIELD	0.051
KGT	18MAY2009	conventional	2	FIELD	0.063
KGT	18MAY2009	conventional	2	FIELD	0.106
KGT	18MAY2009	conventional	2	FIELD	0.085
KGT	18MAY2009	conventional	2	FIELD	0.072
KGT	18MAY2009	conventional	2	FIELD	0.057
KGT	18MAY2009	conventional	2	FIELD	0.038
KGT	18MAY2009	conventional	2	FIELD	0.057
KGT	17JUN2009	30daypost	1	FIELD	1.822
KGT	17JUN2009	30daypost	1	FIELD	1.564
KGT	17JUN2009	30daypost	1	FIELD	0.821
KGT	17JUN2009	30daypost	1	FIELD	0.345
KGT	17JUN2009	30daypost	1	FIELD	0.388
KGT	17JUN2009	30daypost	1	FIELD	2.570
KGT	17JUN2009	30daypost	1	FIELD	2.158
KGT	17JUN2009	30daypost	1	FIELD	1.275

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
KGT	17JUN2009	conventional	2	FIELD	0.015
KGT	17JUN2009	conventional	2	FIELD	0.112
KGT	17JUN2009	conventional	2	FIELD	0.035
KGT	17JUN2009	conventional	2	FIELD	0.037
KGT	17JUN2009	conventional	2	FIELD	0.089
KGT	17JUN2009	conventional	2	FIELD	0.108
KGT	17JUN2009	conventional	2	FIELD	0.127
KGT	17JUN2009	conventional	2	FIELD	0.112
SHP	22MAY2009	30daypost	1	FIELD	0.046
SHP	22MAY2009	30daypost	1	FIELD	0.038
SHP	22MAY2009	30daypost	1	FIELD	0.038
SHP	22MAY2009	30daypost	1	FIELD	0.042
SHP	22MAY2009	30daypost	1	FIELD	0.049
SHP	22MAY2009	30daypost	1	INLET	0.029
SHP	22MAY2009	30daypost	1	OUTLET	0.038
SHP	22MAY2009	30daypost	2	FIELD	0.012
SHP	22MAY2009	30daypost	2	FIELD	0.029
SHP	22MAY2009	30daypost	2	FIELD	0.044
SHP	22MAY2009	30daypost	2	FIELD	0.031
SHP	22MAY2009	30daypost	2	FIELD	0.036
SHP	22MAY2009	30daypost	2	FIELD	0.036
SHP	22MAY2009	30daypost	2	FIELD	0.044
SHP	22MAY2009	30daypost	2	INLET	0.027
SHP	22MAY2009	30daypost	2	OUTLET	0.027
SHP	22MAY2009	30daypost	3	FIELD	0.053
SHP	22MAY2009	30daypost	3	FIELD	0.057
SHP	22MAY2009	30daypost	3	FIELD	0.025
SHP	22MAY2009	30daypost	3	FIELD	0.040
SHP	22MAY2009	30daypost	3	FIELD	0.029
SHP	22MAY2009	30daypost	3	INLET	0.027
SHP	22MAY2009	30daypost	3	OUTLET	0.021
SHP	22MAY2009	30daypost	4	FIELD	0.025
SHP	22MAY2009	30daypost	4	FIELD	0.034
SHP	22MAY2009	30daypost	4	FIELD	0.014
SHP	22MAY2009	30daypost	4	FIELD	0.021
SHP	22MAY2009	30daypost	4	FIELD	0.016
SHP	22MAY2009	30daypost	4	INLET	0.038
SHP	22MAY2009	30daypost	4	OUTLET	0.029
SHP	22MAY2009	conventional	1	FIELD	0.183
SHP	22MAY2009	conventional	1	FIELD	0.025
SHP	22MAY2009	conventional	1	FIELD	0.038
SHP	22MAY2009	conventional	1	FIELD	0.121
SHP	22MAY2009	conventional	1	FIELD	0.083

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
SHP	22MAY2009	conventional	1	FIELD	0.334
SHP	22MAY2009	conventional	1	OUTLET	0.038
SHP	22MAY2009	conventional	2	FIELD	0.070
SHP	22MAY2009	conventional	2	FIELD	0.042
SHP	22MAY2009	conventional	2	FIELD	0.057
SHP	22MAY2009	conventional	2	FIELD	0.102
SHP	22MAY2009	conventional	2	FIELD	0.142
SHP	22MAY2009	conventional	2	INLET	0.027
SHP	22MAY2009	conventional	2	OUTLET	0.025
SHP	22MAY2009	conventional	3	FIELD	0.025
SHP	22MAY2009	conventional	3	FIELD	0.051
SHP	22MAY2009	conventional	3	FIELD	0.016
SHP	22MAY2009	conventional	3	FIELD	0.025
SHP	22MAY2009	conventional	3	FIELD	0.023
SHP	22MAY2009	conventional	3	OUTLET	0.029
SHP	22MAY2009	conventional	3	SOURCE	0.119
SHP	05JUN2009	30daypost	1	FIELD	0.030
SHP	05JUN2009	30daypost	1	FIELD	0.050
SHP	05JUN2009	30daypost	1	FIELD	0.185
SHP	05JUN2009	30daypost	1	FIELD	0.028
SHP	05JUN2009	30daypost	1	FIELD	0.024
SHP	05JUN2009	30daypost	1	FIELD	0.043
SHP	05JUN2009	30daypost	2	FIELD	0.026
SHP	05JUN2009	30daypost	2	FIELD	0.181
SHP	05JUN2009	30daypost	2	FIELD	0.033
SHP	05JUN2009	30daypost	2	FIELD	0.117
SHP	05JUN2009	30daypost	2	FIELD	0.030
SHP	05JUN2009	30daypost	2	FIELD	0.099
SHP	05JUN2009	30daypost	3	FIELD	0.063
SHP	05JUN2009	30daypost	3	FIELD	0.050
SHP	05JUN2009	30daypost	3	FIELD	0.082
SHP	05JUN2009	30daypost	4	FIELD	0.080
SHP	05JUN2009	30daypost	4	FIELD	0.026
SHP	05JUN2009	30daypost	4	FIELD	0.058
SHP	05JUN2009	30daypost	4	FIELD	0.054
SHP	05JUN2009	30daypost	4	FIELD	0.024
SHP	05JUN2009	30daypost	4	FIELD	0.030
SHP	05JUN2009	conventional	1	FIELD	0.883
SHP	05JUN2009	conventional	1	FIELD	0.121
SHP	05JUN2009	conventional	1	FIELD	0.028
SHP	05JUN2009	conventional	1	FIELD	0.043
SHP	05JUN2009	conventional	1	FIELD	0.099
SHP	05JUN2009	conventional	1	FIELD	0.037

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
SHP	05JUN2009	conventional	2	FIELD	0.065
SHP	05JUN2009	conventional	2	FIELD	0.033
SHP	05JUN2009	conventional	2	FIELD	0.045
SHP	05JUN2009	conventional	2	FIELD	0.203
SHP	05JUN2009	conventional	2	FIELD	0.104
SHP	05JUN2009	conventional	2	FIELD	0.164
SHP	05JUN2009	conventional	3	FIELD	0.076
SHP	05JUN2009	conventional	3	FIELD	0.069
SHP	05JUN2009	conventional	3	FIELD	0.050
SHP	05JUN2009	conventional	3	FIELD	0.127
SHP	05JUN2009	conventional	3	FIELD	0.030
SHP	05JUN2009	conventional	3	FIELD	0.037
STM	26MAY2009	30daypost	2	FIELD	0.020
STM	26MAY2009	30daypost	2	FIELD	0.022
STM	26MAY2009	30daypost	2	FIELD	0.043
STM	26MAY2009	30daypost	2	FIELD	0.039
STM	26MAY2009	30daypost	2	FIELD	0.020
STM	26MAY2009	30daypost	2	FIELD	0.065
STM	26MAY2009	30daypost	2	FIELD	0.035
STM	26MAY2009	30daypost	2	FIELD	0.045
STM	26MAY2009	30daypost	3	FIELD	0.033
STM	26MAY2009	30daypost	3	FIELD	0.013
STM	26MAY2009	30daypost	3	FIELD	0.020
STM	26MAY2009	30daypost	3	FIELD	0.043
STM	26MAY2009	30daypost	3	FIELD	0.022
STM	26MAY2009	30daypost	3	FIELD	0.017
STM	26MAY2009	30daypost	3	FIELD	0.026
STM	26MAY2009	30daypost	3	FIELD	0.024
STM	26MAY2009	conventional	1	FIELD	0.104
STM	26MAY2009	conventional	1	FIELD	0.136
STM	26MAY2009	conventional	1	FIELD	0.037
STM	26MAY2009	conventional	1	FIELD	0.033
STM	26MAY2009	conventional	1	FIELD	0.233
STM	26MAY2009	conventional	1	FIELD	0.073
STM	26MAY2009	conventional	1	FIELD	0.091
STM	26MAY2009	conventional	1	FIELD	0.071
STM	26MAY2009	conventional	4	FIELD	0.162
STM	26MAY2009	conventional	4	FIELD	0.065
STM	26MAY2009	conventional	4	FIELD	0.050
STM	26MAY2009	conventional	4	FIELD	0.121
STM	26MAY2009	conventional	4	FIELD	0.045
STM	26MAY2009	conventional	4	FIELD	0.211
STM	26MAY2009	conventional	4	FIELD	0.037

Site	Date	P Application	Check	Type	PO_4-P mg L^{-1}
STM	26MAY2009	conventional	4	FIELD	0.052
STM	26MAY2009	conventional	4	SOURCE	0.007
STM	17JUN2009	30daypost	2	FIELD	0.028
STM	17JUN2009	30daypost	2	FIELD	0.022
STM	17JUN2009	30daypost	2	FIELD	0.020
STM	17JUN2009	30daypost	2	FIELD	0.015
STM	17JUN2009	30daypost	2	FIELD	0.065
STM	17JUN2009	30daypost	2	FIELD	0.050
STM	17JUN2009	30daypost	3	FIELD	0.117
STM	17JUN2009	30daypost	3	FIELD	0.007
STM	17JUN2009	30daypost	3	FIELD	0.086
STM	17JUN2009	30daypost	3	FIELD	0.039
STM	17JUN2009	30daypost	3	FIELD	0.095
STM	17JUN2009	30daypost	3	FIELD	0.108
STM	17JUN2009	conventional	1	FIELD	0.097
STM	17JUN2009	conventional	1	FIELD	0.026
STM	17JUN2009	conventional	1	FIELD	0.058
STM	17JUN2009	conventional	1	FIELD	0.097
STM	17JUN2009	conventional	1	FIELD	0.063
STM	17JUN2009	conventional	1	FIELD	0.099
STM	17JUN2009	conventional	4	FIELD	0.164
STM	17JUN2009	conventional	4	FIELD	0.039
STM	17JUN2009	conventional	4	FIELD	0.013
STM	17JUN2009	conventional	4	FIELD	0.086
STM	17JUN2009	conventional	4	FIELD	0.123
STM	17JUN2009	conventional	4	FIELD	0.082

Appendix 2. Daily temperature data inside test buckets for field experiments with Hydrothol 191. Some experiments were run concurrently at the same location.

Experiment(s)	Date	Mean Daily Temperature (C)	Minimum Daily Temperature (C)	Maximum Daily Temperature (C)
1	03JUN2009	28.2	19.9	36.6
1	04JUN2009	22.0	14.7	31.3
1	05JUN2009	19.0	12.7	29.8
1	06JUN2009	21.7	14.4	31.9
1	07JUN2009	22.9	13.4	36.3
1	08JUN2009	23.1	13.3	37.9
2	03JUN2009	28.2	19.9	36.6
2	04JUN2009	22.0	14.7	31.3
2	05JUN2009	19.0	12.7	29.8
2	06JUN2009	21.7	14.4	31.9
2	07JUN2009	22.9	13.4	36.3
2	08JUN2009	23.1	13.3	37.9
2	09JUN2009	20.8	12.2	33.6
3 and 4	08JUN2009	23.1	13.3	37.9
3 and 4	09JUN2009	20.8	12.2	33.6
3 and 4	10JUN2009	21.4	13.5	35.6
3 and 4	11JUN2009	22.7	13.4	37.6
3 and 4	12JUN2009	21.8	12.4	37.7
3 and 4	13JUN2009	21.5	12.8	36.1
3 and 4	14JUN2009	22.0	11.9	40.0
3 and 4	15JUN2009	21.9	12.6	35.3
5 and 6	09JUN2009	20.8	12.2	33.6
5 and 6	10JUN2009	21.4	13.5	35.6
5 and 6	11JUN2009	22.7	13.4	37.6
5 and 6	12JUN2009	21.8	12.4	37.7
5 and 6	13JUN2009	21.5	12.8	36.1
5 and 6	14JUN2009	22.0	11.9	40.0
5 and 6	15JUN2009	21.9	12.6	35.3
5 and 6	16JUN2009	22.9	14.2	35.3
7 and 8	15JUN2009	21.9	12.6	35.3
7 and 8	16JUN2009	22.9	14.2	35.3
7 and 8	17JUN2009	24.7	15.2	38.6
7 and 8	18JUN2009	26.7	16.6	42.6
7 and 8	19JUN2009	25.8	16.4	38.8
7 and 8	20JUN2009	22.1	14.6	34.7
7 and 8	21JUN2009	22.5	12.3	39.5
7 and 8	22JUN2009	23.6	12.7	42.9
9 and 10	16JUN2009	22.9	14.2	35.3
9 and 10	17JUN2009	24.7	15.2	38.6
9 and 10	18JUN2009	26.7	16.6	42.6
9 and 10	19JUN2009	25.8	16.4	38.8
9 and 10	20JUN2009	22.1	14.6	34.7

Experiment(s)	Date	Mean Daily Temperature (C)	Minimum Daily Temperature (C)	Maximum Daily Temperature (C)
9 and 10	21JUN2009	22.5	12.3	39.5
9 and 10	22JUN2009	23.6	12.7	42.9
9 and 10	23JUN2009	25.4	13.7	45.3
11 and 12	23JUN2009	25.4	13.7	45.3
11 and 12	24JUN2009	27.0	15.1	42.5
11 and 12	25JUN2009	25.4	14.7	39.5
11 and 12	26JUN2009	25.5	13.5	40.9
11 and 12	27JUN2009	28.0	16.7	44.3
11 and 12	28JUN2009	29.4	19.0	45.5
11 and 12	29JUN2009	28.5	18.1	45.7
11 and 12	30JUN2009	23.3	14.5	40.6
13 and 14	22JUN2009	23.6	12.7	42.9
13 and 14	23JUN2009	25.4	13.7	45.3
13 and 14	24JUN2009	27.0	15.1	42.5
13 and 14	25JUN2009	25.4	14.7	39.5
13 and 14	26JUN2009	25.5	13.5	40.9
13 and 14	27JUN2009	28.0	16.7	44.3
13 and 14	28JUN2009	29.4	19.0	45.5
13 and 14	29JUN2009	28.5	18.1	45.7
13 and 14	30JUN2009	23.3	14.5	40.6
13 and 14	01JUL2009	17.7	16.0	19.9