Evaluation of Barley Straw as an Alternative Algal Control Method in Northern California Rice Fields

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ABSTRACT

California rice fields are shallow water systems with depths usually less than 15 cm. Excessive algal growth often characterizes a significant proportion of them. Especially troublesome are species of green algae and cyanobacteria that interfere with rice growth by becoming entangled with the seedlings and subsequently uprooting them when the algal mats dislodge from the sediment. We sought to determine if barley straw would reduce excessive algal biomass during the crucial 30-day period of seedling establishment following initial flooding of the field. We conducted experiments in 2005 and 2006 in northern California rice fields. Algae dry weight varied considerably ranging from 0 to 286 g m^{-2}. Relative to controls, mean dry weight of algae was not affected by barley straw in either of the experiments. Measured water temperatures in the 2005 and 2006 experiments were greater than the 20°C threshold for decomposition of the barley straw and production of a hypothesized growth-inhibiting chemical, for a considerable portion of the experimental period. We conclude that adding barley straw into a rice field did not reduce the abundance of algae during the critical period when algal growth is most troublesome for rice culture.

Key words: algae management, *Hydrodictyon*, *Pithophora*, *Nostoc spongiaeforme*, *Hordeum vulgare*, agroecosystem.

INTRODUCTION

In 2004, nearly 235,000 ha of rice (*Oryza sativa* L.) were grown in California with the vast majority of it grown in the Sacramento Valley. California rice fields are shallow with water depths usually less than 15 cm, and excessive algal growth often characterizes a significant portion of them. Mat-forming species of green algae (e.g., *Rhizoclonium* and *Hydrodictyon*) and cyanobacteria (e.g., *Nostoc spongiaeforme*) (Spencer et al. 2006) interfere with rice growth by becoming entangled with the seedlings and subsequently uprooting them when the mats dislodge from the sediment. In some cases, planktonic green algae and cyanobacteria (blue-green algae) can form blooms that shade and even cling to the developing rice seedlings (Spencer et al. 2006). These problems are most troublesome during the 30-day period following the spring flooding of rice fields.

Copper sulfate is applied aerially to manage algal problems in rice fields. However, growers have observed in recent years that algal populations may not be as inhibited by copper sulfate treatments as they have been in the past.[4] Barley straw (*Hordeum vulgare*) has been identified as an effective method for reducing algal growth in a variety of aquatic systems within the United Kingdom (Welch et al. 1990, Everall and Lees 1997, Harriman et al. 1997). It has been reported to be effective against species of filamentous green algae (Caffrey and Monahan 1999, Gibson et al. 1990), cyanobacteria (referred to as "blue-green algae") (Ball et al. 2001, Barrett et al. 1996, 1999, Martin and Ridge 1999, Ridge and Pillinger 1996, Newman and Barrett 1993, Gibson et al. 1990), and diatoms (Barrett et al. 1996, 1999), all of which occur in California rice fields (Spencer et al. 2006). The impact of barley straw on reducing or inhibiting algal growth varies. For example, Everall and Lees (1996) reported that water column chlorophyll values in the year of treatment were 40% of those in the year preceding treatment in a Derbyshire reservoir. This was a 60% reduction in algal biomass. Caffrey and Monahan (1999) applied bales of barley straw in an Irish canal. They reported that "as long as rotted straw was present, no filamentous algae were recorded" and recorded zero values for filamentous algae biomass in the treated sections of the canal. Barrett et al. (1996) reported that algal cell counts were reduced to about 25% of their previous levels one year after treatment with barley straw and that blooms of cyanobacteria were almost completely eliminated. So, barley straw application might be expected to considerably reduce or eliminate entirely algal populations depending on the system that was treated. In the case of California rice fields colonial cyanobacteria (blue-green algae) and filamentous green algae are the nuisance types.

The amount of barley straw required to reduce algal growth has been examined by Barrett et al. (1999) who applied barley straw to a 25-ha water supply reservoir in Scotland from 1993 to 1998. They added amounts of barley straw equivalent to 60, 64, 76, 92, 120, and 250 kg ha^{-1}. Barrett et al. (1999) reported that 60 kg ha^{-1} was at the low end of the effective range for barley straw. Information Sheet 3 published by the Centre for Aquatic Plant Management indicates that amounts as high as 1000 kg ha^{-1} may be required but recommends using 250 kg

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ha^{-1} of barley straw (Centre for Aquatic Plant Management, undated), especially in the early stages of treatment. Higher rates are more costly and may be associated with low oxygen conditions brought on by decomposition of the straw.

As part of a search for alternative algal management strategies that might be used by rice growers, we sought to determine if barley straw would reduce excessive algal biomass during the crucial 30-day period of seedling establishment following initial flooding of the rice field. To do this, we conducted two field experiments, one in 2005 and one in 2006, in which barely straw was evaluated in plots within working rice fields at the rate of 250 kg ha^{-1}.

MATERIALS AND METHODS

The 2005 experiment was smaller in scale and conducted in a rice field near Pleasant Grove, Sutter County, California (N 38°50’5.636”, W121°31’46.848”) during May-June. For this experiment, plots were established along one side of a rice field that was being managed as a conventional full season flooded field for rice production. The plots were 9.1 m wide by 18.3 m long and were surrounded on three sides by a 0.4 m high berm of soil. The fourth side consisted of the bank edge of the rice field. Each plot had an opening to the rice field so that the plot could be flooded. Following flooding the opening was sealed by inserting a metal sheet into the soil and the adjacent berm. Three plots had 3.4 kg (equivalent of 250 kg ha^{-1}) of barley straw added to them and two plots served as untreated controls (Figure 1). The barley straw for each plot was loosely packed into “pillows” made with 6 mm mesh hardware cloth. This allowed the straw to come into contact with the water while being contained. Barley straw pillows were placed at opposite diagonal corners of the plot prior to flooding. Plots were flooded on May 31, 2005. Water was about 15 cm deep and it covered about 95% of the pillow’s height. In this experiment the control plots did not have barley straw added to them, nor did they have empty “pillows” added to account for any effects that might be due to the hardware cloth structure. So, the algae growing in the control plots experienced the conditions that prevail in the open water. Just prior to filling, the north one-third of each plot received a copper sulfate treatment (16.8 kg ha^{-1} which is equivalent to 1.5 mg L^{-1} of copper ion). After three weeks, we collected the floating mats of algae from within one randomly placed 0.5 m by 0.5 m quadrat within the south one-third of each plot using a metal mesh “strainer.” The algal material was placed in a paper bag, returned to the laboratory, and dried for 48 h at 80°C, after which it was weighed. Water temperature was recorded hourly by a Watchdog® data logger (Spectrum Technologies, Plainfield, IL) placed in one of the plots. We calculated mean daily air temperature and total daily solar radiation using data from station Nicolaus.A (located in Nicolaus, California about 15 km from the rice field) from the UC Impact Weather database (http://ipm.ucdavis.edu). We tested the hypothesis that dry weight of algae in barley straw treated plots was different from that in untreated control plots using a Student’s t-test using the Statistical Analysis System (SAS Institute, Inc. 1999).

A second experiment was conducted in a rice field located just west of Highway 99 in Butte County, California (N39°27’29.945”, W121°41’59.345”) in May-June, 2006. During this experiment the field was used for rice production and was being managed as a conventional full season flooded field. Also, during this period an application of copper sulfate (nominal rate 1 mg L^{-1} as copper) was made by the grower to the entire field for algal control. It should also be noted that rice fields commonly have partially decomposed rice straw from the previous growing season present in them. This was the case for this field as well.

Figure 1. The upper picture is of a 2005 experimental plot with barley straw pillows in place. Lower picture shows the placement of barley and rice straw wattles and sample point flags in the 2006 experiment.

In the second experiment we established 32, 14.6 m by 14.6 m square plots adjacent to the sides of the rice field. These plots were not separated from either the field or adjacent plots by berms. (As the experiment was conducted in an active rice field the experimental setup was constrained by the desire to minimize interference with normal rice culture procedures.) In the center of each plot we placed one wattle filled with either barley straw or rice straw. We purchased wattles filled with barley straw from Nevada County Farm Supply, Grass Valley, California. The wattles consisted of 4.6 kg ± 0.18

kg (standard error, N = 16) of barley straw encased in plastic mesh netting. The wattles were approximately 1.3 m long and 0.18 m in diameter. Using the rate of 250 kg ha^{-1} of barley straw (Centre for Aquatic Plant Management, undated), each wattle would be expected to be sufficient to treat a square that is 14.6 m on each side. We placed similar sized wattles (1.3 m by 0.15 m diameter) filled with rice straw at the center of plots that were designated as untreated controls.

In this experiment, we used a rice straw wattle as a control to account for effects due to the plastic netting material surrounding the wattle, the presence of wooden stakes to hold the wattles in place, the possible effects that the physical structure of the wattle might cause due to interactions with the wind, such as causing wind-blown algal mats to collect adjacent to it, possible effects that straw may have on binding nutrients in the surrounding water, and the effect that providing additional substrate or nutrients may have on the abundance of microscopic organisms including invertebrate herbivores, such as rotifers, which feed on algae. It has long been known, for example, that adding a "bale of hay" to a pond often reduces algal blooms (Ross and Lembi 1985, Centre for Aquatic Plant Management, un-dated). Since the species composition of a "bale of hay" was never stated in the popular literature, just its presence could have had an impact on algal populations and justifies our use of rice straw wattles as controls.

To prevent the wattles from moving due to wind action, we drove 1 m wooden stakes into the end of each wattle. The wattles were deployed into the field on May 19, 2006, prior to flooding. Adjacent to each wattle and at about 0.6 m intervals from the bank going out toward the center of the field we placed 2 rows of 5 plastic flags each (Figure 1). Thus there were 10 plastic flags, 5 on either side of each wattle, at which algal samples were later collected. The rows of flags were put in place when the field was still dry and were on average 4.4 m from the adjacent wattle. No algae were visible on the dry soil. The field was filled with water immediately afterwards (5:00 PM PDT, May 19, 2006). The water was deep enough that it covered about 75% of the wattles' diameter. When we returned after one week to check on the wattles, we noticed that several had been burrowed into by rodents apparently for the purpose of obtaining nesting materials. Fortunately, the straw was still mostly in place. We fashioned covers out of 6 mm mesh hardware cloth which we placed over the top of each wattle. This prevented further disruption by animals.

On two dates (June 1, 2006 and June 15, 2006) we used a 15 cm diameter mesh strainer attached to an extendable aluminum pole (extended to 5.3 m) to collect all floating algae present within a 0.3 m radius of each flag. The algal material was returned to the laboratory and dried for 48 h at 80 C, after which it was weighed.

We placed three Tidbit ® data loggers (Onset Computer Corporation, Bourne, MA) into the field to record water temperature at 60 minute intervals from 5 PM on May 19 to 7 AM on June 22, 2006. We calculated mean daily air temperature and total daily solar radiation using data from station Durham (about 18 km from the rice field) from the UC Impact Weather database (http://ipm.ucdavis.edu). We used these as the independent variables in regression equations (SAS Institute Inc.1999) to test their predictive capabilities for mean daily rice field water temperature (calculated over all three sites).

On June 22, 2006, we collected algal samples that were preserved with Lugol's solution for later identification. We tested the hypothesis that barley straw reduced the presence of algae by comparing algal abundance adjacent to 160 barley and 160 rice straw wattles on June 1 (13 days after flooding) and June 15, 2006 (28 days after flooding). We used the procedures in SAS (SAS Institute, Inc. 1999) to calculate a t-test for each sample date. If the variances were unequal, we used the Satterthwaite adjusted degrees of freedom for the t-statistic.

RESULTS AND DISCUSSION

For the 2005 experiment, algal abundance varied from 2.3 to 29.7 g m^{-2}. Results of Student's t-test indicate that there was no significant difference ($t = 0.17$, $df = 3$, $P = 0.87$) in algal dry weight for plots which received the barley straw treatment (14.1 g m^{-2}) compared to those that did not (11.9 g m^{-2}). In this case the control represents the conditions present in the open water of the plot. Algae dry weights were within the range of values (0 to 153 g m^{-2}) previously reported for California rice fields (Spencer et al. 2006).

For the 2006 experiment, the dry weight of algae present at the sampling points which were 4.4 m from the adjacent barley straw or rice straw wattles varied considerably ranging from 0 to 286 g m^{-2}. The mean dry weight of algae was not affected by the type of straw (barley or rice) present in the adjacent wattles (Figure 2). This was true for both sampling dates. Although, the mean values in Figure 2 are small, due

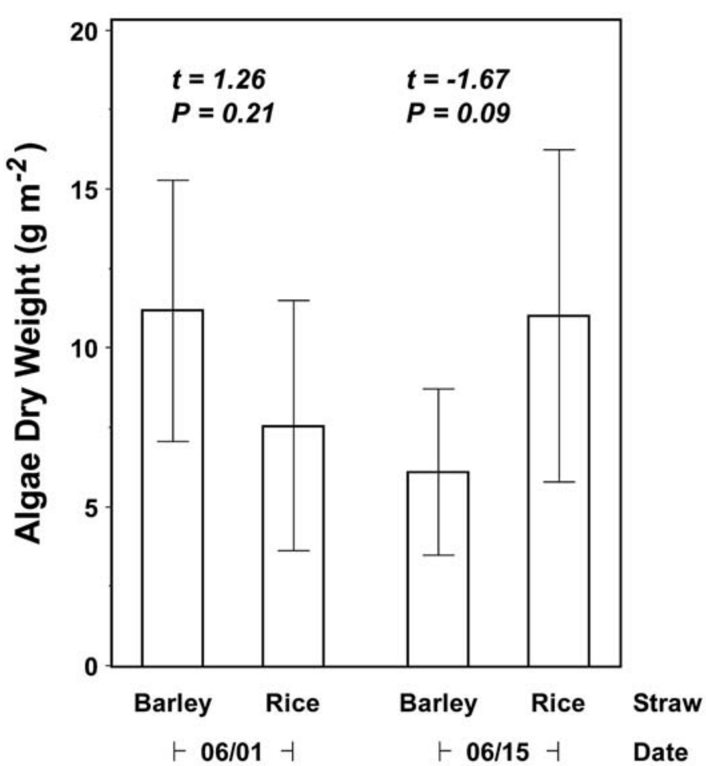

Figure 2. Mean dry weight (g m^{-2}) ± 95% confidence intervals for algae within 0.3 m radius of each flag on two dates in a northern California rice field. There were 10 flags adjacent to each barley or rice straw wattle for a total of 320 samples. Results of a t-test for each date are also included in the figure.

to the presence of many 0 values, the algae dry weights at the sampling points were within the range of values (0 to 153 g m^{-2}) previously reported for other California rice fields (Spencer et al. 2006). They also agree with data on the abundance of the filamentous green alga, *Pithophora oedogonia*, which ranged from 78 to 163 g m^{-2} in an infested Indiana lake (O'Neal et al. 1985).

Thus we conclude that adding barley straw into a rice field did not reduce the abundance of algae present within the critical period when algal growth is most troublesome for rice culture, and this approach is likely not a viable strategy for controlling algae in these agroecosystems.

In the 2005 experiment, water temperature varied from 12.1 to 37.9°C (Table 1). Mean and maximum daily water temperatures were greater than 20°C on 17 of 22 days. Table 1 indicates that the minimum water temperature was less than 20°C on all days. Mean daily water temperature was significantly related to mean daily air temperature (Table 3). In the 2006 experiment, water temperature also varied spatially within the rice field (Table 2). In contrast with the 2005 results, mean daily water temperature for the entire field was related to both mean daily air temperature and total daily solar radiation (Table 3). The mean water temperature was 21.1, 25.1, and 26.3 C at sites 1 through 3, respectively. Additionally, Table 2 indicates that the minimum water temperature was greater than 20°C on 1, 16, and 22 days of 31 days measured at site 1, site 2, and site 3, respectively. Similarly, the maximum water temperature was greater than 20°C on 29, 31, and 31 days of 31 days measured at site 1, site 2, and site 3, respectively.

Information Sheet 3 published by the Centre for Aquatic Plant Management indicates that the barley straw decomposition process is temperature dependent and occurs faster in warmer water. At cooler water temperatures (i.e., less than 10°C), it takes approximately six to eight weeks for the decomposing straw to yield sufficient quantities of the growth-inhibiting chemical to effectively control algae. Conversely, it may only require one to two weeks when the water temperature is above 20°C. For example Everall and Lees (1997) reported reductions in phytoplankton abundance 12 days after application of barley straw. Since the water temperatures in the rice fields were greater than the 20°C threshold for a considerable portion of the experimental period, we expected that the growth-inhibiting chemical(s) released by decomposing barley straw should have been present in quantities sufficient to reduce algal growth in these fields, especially since the algal samples were collected at points within 5 m of the barley straw wattles. It seems reasonable to expect that an inhibitory substance would have been at a high concentration near the barley straw wattles. This does not appear to have been the case in this experiment. While the mechanism for barley straw inhibition of algae is not known for certain, Caffrey and Monahan (1999) state that decomposing barley straw apparently releases unstable, short-lived algal inhibitors possibly derived from oxidized polyphenolic compounds into the surrounding water (see also Everall and Lees 1997, Pillinger et al. 1994, Ridge and Pillinger 1996). Daytime dissolved oxygen concentrations averaged 10.9 mg L^{-1} in California rice fields surveyed by Spencer et al. (2006), suggesting that conditions favoring oxidation of the straw compounds were present.

In both experiments, copper sulfate was applied once to the areas used, including both the control and barley straw treated areas. This raises the possibility that copper interfered with the growth of the microbes involved in the decomposition of barley straw. While the role of microbes in barley

TABLE 1. WATER TEMPERATURE (°C) WITHIN THE RICE FIELD, AND AIR TEMPERATURE AND SOLAR RADIATION AT A WEATHER STATION APPROXIMATELY 15 KM FROM THE FIELD, FOR THE 2005 EXPERIMENT. "N/A" INDICATES THAT DATA WERE NOT COLLECTED.

	Water temperature (°C)		Air temperature (°C)		Solar radiation
Date	Minimum	Maximum	Minimum	Maximum	Watts m^{-2}
05/31/05	n/a	n/a	14.4	31.7	314
06/01/05	n/a	n/a	13.3	30.6	339
06/02/05	16.4	36.2	13.3	29.4	337
06/03/05	13.3	35.8	12.2	31.7	337
06/04/05	13.3	34.9	12.8	31.7	328
06/05/05	12.1	34.5	11.7	25.0	307
06/06/05	14.1	34.1	8.3	24.4	323
06/07/05	14.4	21.3	6.7	23.9	331
06/08/05	16.4	30.3	12.2	18.3	95
06/09/05	17.1	36.6	15.0	25.0	219
06/10/05	17.1	35.8	13.3	30.0	314
06/11/05	17.1	34.9	13.9	30.6	328
06/12/05	18.3	37.9	12.2	31.1	337
06/13/05	15.2	37.9	12.8	33.9	326
06/14/05	13.7	36.6	16.1	32.8	324
06/15/05	12.5	19.1	12.2	30.6	318
06/16/05	14.1	25.6	12.8	18.3	107
06/17/05	14.4	28.3	11.1	21.7	257
06/18/05	15.6	32.4	12.2	23.3	269
06/19/05	16.0	34.9	10.6	26.1	330
06/20/05	15.2	33.2	11.7	28.3	326
06/21/05	16.0	36.6	12.8	28.9	319

TABLE 2. WATER TEMPERATURE (°C) AT THREE SITES WITHIN THE RICE FIELD, AND AIR TEMPERATURE AND SOLAR RADIATION AT A WEATHER STATION APPROXIMATELY 18 KM FROM THE FIELD, FOR THE 2006 EXPERIMENT.

	Water temperature (°C) at Site 1		Water temperature (°C) at Site 2		Water temperature (°C) at Site 3		Air temperature (°C)		Solar radiation
Date	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Minimum	Maximum	Watts m^{-2}
05/21/06	17.3	23.4	18.8	23.7	17.2	23.9	15.0	21.1	124
05/22/06	15.8	25.6	16.4	25.3	16.6	28.8	13.3	21.7	258
05/23/06	15.5	29.0	16.1	28.3	16.9	30.9	13.9	22.8	258
05/24/06	16.4	30.0	17.3	29.0	18.1	32.0	12.2	23.9	291
05/25/06	16.1	32.8	17.0	31.8	17.2	33.8	12.8	25.0	319
05/26/06	14.9	32.8	16.1	30.4	15.4	32.7	11.7	21.7	301
05/27/06	14.3	31.4	14.7	30.4	15.4	31.3	7.2	21.7	345
05/28/06	17.6	19.4	17.0	32.5	16.3	33.5	7.2	23.9	349
05/29/06	17.3	20.9	17.9	31.4	18.7	32.7	7.2	27.2	351
05/30/06	17.0	31.8	19.7	32.5	20.5	33.5	7.2	29.4	344
05/31/06	17.9	28.6	20.3	32.5	20.8	34.6	11.1	30.6	311
06/01/06	17.9	28.3	21.2	29.0	22.6	30.2	17.2	28.9	237
06/02/06	20.0	32.5	20.9	31.8	21.4	34.6	18.9	30.0	280
06/03/06	19.1	36.2	21.5	34.7	23.0	36.1	17.2	32.8	318
06/04/06	18.5	31.4	21.5	33.3	23.6	36.5	16.7	30.0	340
06/05/06	18.5	32.8	20.6	34.7	23.3	36.1	14.4	31.7	348
06/06/06	18.5	31.8	21.8	35.5	23.9	36.5	15.0	31.7	344
06/07/06	18.2	29.6	23.1	34.0	24.9	36.5	16.7	31.1	335
06/08/06	18.2	31.4	18.2	32.2	21.7	34.6	13.9	26.7	328
06/09/06	18.2	31.8	20.6	34.7	22.3	36.9	12.2	31.1	336
06/10/06	18.2	27.6	19.7	31.4	22.3	34.2	13.3	28.3	292
06/11/06	18.2	27.3	20.6	31.1	22.6	32.7	15.6	26.7	281
06/12/06	18.2	25.3	19.1	27.3	21.7	30.2	13.9	23.3	288
06/13/06	18.2	23.4	18.8	26.3	20.8	29.2	13.3	22.8	262
06/14/06	18.2	22.4	18.8	26.7	20.8	28.2	10.0	23.3	230
06/15/06	18.2	23.4	20.3	31.1	21.7	32.0	11.1	31.1	339
06/16/06	18.2	23.7	21.8	32.5	23.6	33.5	15.6	36.7	348
06/17/06	18.2	25.0	22.2	34.4	24.2	35.3	13.9	35.0	351
06/18/06	18.2	18.5	23.1	34.7	24.6	36.1	14.4	33.3	342
06/19/06	18.2	23.1	21.2	32.5	23.0	32.0	13.9	31.7	348
06/20/06	18.2	23.4	23.7	33.3	24.9	31.6	13.3	36.1	350

straw decomposition and production of an algal inhibitor is not known for certain, Pillinger et al. (1992) evaluated fungi from 18 genera isolated from rotting barley straw and reported that the algal inhibitor produced by barley straw was not explained by antialgal properties of a unique mycoflora associated with barley straw or any specific fungi. The toxicity of copper is dependent upon the presence of the copper ion, Cu^{2+}. When copper sulfate is applied to natural waters the vast majority of copper is bound by naturally occurring dissolved organic compounds within 24 hours (McKnight 1982). Newly flooded rice fields have abundant organic matter in the form of rice straw residue from the previous growing season and a similar copper ion binding mechanism would be expected to apply. The abundant growth of algae in these fields indicated by the high biomass values suggest that microscopic algae and cyanobacteria were not affected by the copper treatment, implying that other microbes may also not have been seriously affected by a 24-hour or less exposure to the copper sulfate treatment. Furthermore, the lack of impact of rotting barley straw on algae was observed in both the 2005 and 2006 experiments, even though only one-third of the area of test plots was treated with copper in the 2005 experiment. Any effect of copper on the barley decomposition process would be expected to have been less in the 2005 experiment since two-thirds of the experimental plot was not treated with copper sulfate. The fact that algal biomass was not reduced in the 2005 experiment argues against reduced barley straw decomposition due to the copper treatment.

In the 2006 experiment, the algal species that were collected at the last sampling were the mat-forming green algae *Hydrodictyon* sp. and *Pithophora*, *Anabaena* sp. (a planktonic cyanobacterium), and *Nostoc spongiformae*, a filamentous cyanobacterium that forms gelatinous masses. Wells et al. (1994) found inconsistent effects of aerobically decomposing barley straw on *Hydrodictyon*, ranging from varying degrees of inhibition to enhanced growth. *Spirogyra* and *Cladophora glomerata* are also mat-forming green algae and both of them have been reported to exhibit reduced growth in the presence of rotting barley straw (Welch et al. 1990, Gibson et al. 1990). In addition Caffrey and Monahan (1999) reported that green filamentous algae (no species names given) were completely eliminated from an Irish canal that was treated with barley straw. *Anabaena flos-aquae* growth was reported to be reduced in the presence of rotting barley straw by Gibson et al. (1990) and Martin and Ridge (1999), but Ferrier et al (2005) reported that it was stimulated. Schrader (2005) evaluated two com-

Table 3. Comparison of regression equations relating mean daily water temperature (C) within two rice fields to mean daily air temperature (C) and total solar radiation (Watts m^{-2}).

Source	Estimate	Standard error	t value	Pr > t	R^2
2005					
Intercept	13.50	4.510	3.00	<0.001	0.23
Mean Air Temperature	0.53	0.230	2.35	<0.001	
Intercept	20.98	2.990	7.02	<0.0001	0.06
Solar Radiation	0.01	0.010	1.03	0.32	
Intercept	13.50	4.620	2.92	<0.01	0.24
Mean Air Temperature	0.59	0.290	2.02	0.06	
Solar Radiation	-0.003	0.011	-0.28	0.78	
2006					
Intercept	14.63	1.510	9.64	<0.0001	0.62
Mean Air Temperature	0.50	0.070	6.91	<0.0001	
Intercept	17.81	1.900	9.36	<0.0001	0.34
Solar Radiation	0.02	0.006	3.84	0.0006	
Intercept	11.57	1.520	7.62	<0.0001	0.75
Mean Air Temperature	0.43	0.060	6.70	<0.0001	
Solar Radiation	0.015	0.004	3.67	0.001	

mercially available forms of barley straw extract and reported that neither killed three species of cyanobacteria. Growth of *Microcystis aeruginosa*, another planktonic cyanobacterium, has been reported to be negatively affected by barley straw by Pillinger et al. (1992), Newman and Barrett (1993), Ridge and Pillinger (1996), Martin and Ridge (1999), Ridge et al. (1999), and Ball et al. (2001), while Choe and Jung (2002) reported variable response for this species. Even though these results vary, based on the species present in this field, it is not unreasonable to have expected to see a reduction in algal growth produced by decomposing barley straw.

Conclusions about the lack of effect of barley straw on rice field algae in these experiments are based on the conditions present in two geographically disparate northern California rice fields for the first three to four weeks following the introduction of water to the field, which is the time when algal impacts on rice seedlings are most serious. However, growing conditions and algal abundances in California rice fields may differ from the reservoir, canal, and lake sites studied by other researchers where barley straw treatments have been most successful (Xu et al. 2002). There may be differences between the composition of barley straw used. It may also be that three to four weeks is insufficient time for the barley straw to have an affect under California conditions. Nevertheless, results of this study agree with previous reports. Ferrier et al. (2005) concluded that the application of barley straw (112 kg ha^{-1}) had no effect on algal growth in six central Maryland ponds. Boylan and Morris (2003) applied three levels of barley straw to enclosures in an Iowa pond and reported that they observed no consistent degree of algal growth inhibition for either filamentous or planktonic forms.

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