BARLEY STRAW - ALGAE CONTROL LITERATURE ANALYSIS

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INTRODUCTION

Evidence has been accumulating since the late 1970's that barley straw can be used to control nuisance blooms of algae in freshwater systems. The most extensive use of this treatment has been in the British Isles, where it has been used in lakes of varying sizes, potable water reservoirs, canals, and streams (Barrett *et al.* 1999, Caffrey and Monahan,1999, Harriman *et al.* 1997, Welch *et al.* 1990). Many of the published accounts report consistent success in preventing nuisance algal blooms where previously such blooms were a regular occurrence. This success has been achieved as long as six years in a row, with no appearance of resistant algae or any other conspicuous change in the species of algae occurring subsequent to application (Barrett *et al.* 1999). Significantly, this suppression of algal blooms has brought with it no apparent damage to invertebrates, fish, or waterfowl, and the growth of macrophytes has sometimes been enhanced. No problems of taste or odor were reported in drinking water supplies treated with barley straw; indeed these problems may be ameliorated by the reduction in algal blooms (Everall and Lees 1997, Barrett *et al.* 1999).

When barley straw has been used in North America, success in controlling algae has not been so consistent, and the reasons for this remain unclear (Nicholls *et al.* 1995, Lembi, 2001, Boylan & Morris 2003). The success of the method depends on a number of factors, all of which must be properly addressed: starting treatment well in advance of bloom development, adequate straw dosage, adequate aeration of the straw, proper positioning of the straw in the body of water, adequate water circulation, and perhaps the type (cultivar) of barley used and the conditions under which the barley was grown. Nevertheless, even in North America barley straw and barley extracts are being widely promoted for eliminating nuisance algal blooms in ornamental ponds (e.g. http://www.pristineponds.com/index.htm; http://www.aquaticeco.com/index.cfm/fuseaction/product.detail/iid/14

90;
http://www.aquaticeco.com/index.cfm/fuseaction/product.detail/iid/1484), and a U.S. patent has been issued for a barley extract used to kill algae (Friedman 2000).

HOW BARLEY STRAW MAY WORK TO SUPPRESS ALGAL GROWTH

It is still not clear exactly how barley straw suppresses algal growth. There may well be more than one mechanism at work. The explanation favored by several authors is that as the straw decomposes ("rots") under aerobic conditions, phenolic compounds such as lignin, and especially oxidized phenolics, are slowly leached into the surrounding water (Everall & Lees 1997, Pillinger *et al.* 1994, Ridge & Pillinger 1996). Both laboratory and field experiments have shown that barley straw releases phenolic substances that both before and after decomposing suppress algal growth (Everall & Lees 1997, Pillinger *et al.* 1994). The straw exudates do not appear to bind nutrients or otherwise make them unavailable, but this factor has not yet been investigated thoroughly.

It is not known why straw from other plants such as wheat have not shown algistatic effects, even though these straws may also contain significant levels of phenolics (Ball *et al.* 2001). This suggests that the kind of phenolics (e.g., there are many different structural forms of lignin) may be important, or perhaps accompanying substances affect the way the phenolics break down. Algistatic effects have also been demonstrated using decomposed leaves of deciduous trees such as oak, which are high in phenolics, and also "brown rotted" wood, which contains colored phenolic substances (Pillinger *et al.* 1995, Ridge & Pillinger 1996, Ridge *et al.* 1999).

An alternative hypothesis for the effect of barley straw in suppressing algae growth focuses on the straw as a carbon source added to a lake system, not as a chemical inhibitor. This hypothesis appeared more reasonable in the absence of detectable phenolic compounds following effective straw application in a Minnesota lake. Barley straw provides a carbon source for carbon-limited microbial growth. With the carbon availability secure, the microbial community production soars - the non-cyanobacteria populations - and phosphorus uptake is shunted through the non-cyanobacterial microbial loop ecosystem. The presence of decaying barley straw therefore results in phosphorus limitation for algae, not inhbitition by a released chemical compound (Anhorn 2005).

Different species of algae have been found to vary widely in their susceptibility to the effects of barley straw (Table 1).

Table 2. Summary of effects of barley straw on algae taxa.

TAXON	SUPPRESSION	SOURCE
Anabaena	does not specify	Molversmyr, A. 2002
Anabaena cylindrica	no	Holz *et al.* 2001
Ankistrodesmus falcatus	yes	Brownlee, E. F. *et al.* 2003
Aphanizomenon	does not specify	Molversmyr, A. 2002
Aphanizomenon flos-aquae	does not specify	Wisniewski, R . 2002
Aphanizomenon flos-aquae	yes	Martin, D. and I. Ridge, 1999; Everall and Lees 1996
Chlorella capsulata	yes	Brownlee, E. F. *et al.* 2003
Chlorella vulgaris	yes	Holz, J.C. *et. al.* 2001
Cladophora glomerata	yes	Welch, I. M. *et. al.* 1990
Cyclotella sp.	no	Brownlee, E. F. *et. al.* 2003.
Cylindrospermum sp.	no	Holz, J. C. *et. al.* 2001.
Eucapsis sp.	no	Holz, J. C. *et. al.* 2001.
Gloeocapsa sp.	slightly	Holz, J. C. *et. al.* 2001.
Isochrysis sp	yes	Brownlee, E. F. *et. al.* 2003.
Microcystis	does not specify	Molversmyr, A. 2002
Microcystis aeruginosa	yes	Martin, D. and I. Ridge. 1999
Microcystis aeruginosa	yes	Newman, Jonathan R. and P. R. F. Barrett. 1993
Microcystis sp.	yes	Ball, Andrew S. *et. al.* 2001.
Prorocentrum minimum	no	Brownlee, E. F. *et. al.* 2003.
Pseudanabaena sp.	no	Brownlee, E. F. *et. al.* 2003.
Scenedesmus	yes	Ball, Andrew S. *et. al.* 2001.

Some cyanobacteria and chlorophyta have been suppressed by barley straw, according to results in Table 1, but taxa of other large algae groups (e.g. diatoms) have not.

These results may be the effect of several poorly-controlled factors in full-scale treatments or in smaller field or laboratory assays. For example:

1) Laboratory experiments often use culture media that are chemically very different from natural waters (e.g. Ball *et al.* 2001, Gibson *et al.* 1990, Holz *et al.* 2001, Martin & Ridge 1999, Ridge & Pillinger 1996).

2) Laboratory experiments usually use cultures of single species of algae, instead of the mix of many species that is invariably found in natural waters. When the cultures were not axenic, the microbial component of the cultures would have been very different from natural waters.

3) Barley straw in different experiments has been used without prior decomposition (Ball *et al.* 2001, Ridge & Pillinger 1996) or decomposed under a variety of different conditions (the details of which cannot always be determined from the authors' descriptions), e.g. with aeration (Pillinger *et al.* 1994) and without (Gibson *et al.* 1990, Martin & Ridge 1999); in darkness (Martin & Ridge 1999) or under fluorescent lighting (Ball *et al.* 2001) or exposed to greenhouse illumination (Gibson *et al.* 1990); at various temperatures for various times at various dosages; in lakewater (Ball *et al.* 2001) or water that differed chemically and certainly microbially from natural waters (e.g. aged tap water, Gibson *et al.* 1990, Ridge & Pillinger 1996).

4) Field treatments have usually employed harvested straw left intact so that it can be retained by netting or the like in the water, whereas laboratory experiments have often been carried out with variously-sized chopped pieces or powdered straw, or straw leachates made by boiling straw, or straw extracted for as long as several weeks under various lighting conditions (almost never with sunlight or other light with significant UV), but usually for much shorter periods than have been found to be effective in the field.

FACTORS AFFECTING THE SUCCESS OF BARLEY STRAW TREATMENT IN NATURAL WATERS

Based on numerous field trials that have shown successful control of algal blooms, these procedures should be followed:

1) Barley straw should be placed in the body of water several months before bloom conditions are expected to occur. This is because straw decomposition must proceed for some weeks before significant algae-suppressing substances are released. In addition, it has been found that even very high doses of straw cannot eliminate a bloom once it has begun. Under British conditions bloom suppression continues for up to six months after straw is placed in the water.

2) An adequate amount of barley straw must be used. This is normally specified in weight of dry straw per unit area or dry straw per unit volume of the body of water.

3) The barley straw must be well-aerated. Therefore bales of straw should only be used in streams with strong currents. Otherwise the straw is usually packed loosely in netting, best configured as long tubes that permit good water flow through the straw and that can be arranged to cover an extended area.

4) The straw must be kept near the water surface, usually by attaching floats to the netting.

5) Distribution of the straw must be reasonably uniform over a large body of water.

Table 2 summarizes the barley straw "dosage" or application rate guidelines that have been reported in field trials.

Table 2. Recommended dose and application conditions for use of barley straw to control algae growth in ponds and reservoirs. The numbers in the Table under Application Conditions refer to the preceding numbers noting conditions in the literature and elsewhere that accompany the recommendations for barley straw doses.

SOURCE	RECOMMENDED DOSE	APPLICATION CONDITIONS
Barrett *et al.* 1999	6.0 – 28.0 g/m^3 ; initial high dose was reduced to doses ranging from 6.0-12.0 g/m^3, with recommendation for 9.0 g/m^3 as effective amount.	Potable water supply reservoir, N. Scotland, 0.025 km^2 (6.18 ac), avg. depth 10 m (32.8 ft), 250,000 m^3 (8.83x10^6 ft^3)/**1,3,4,5**
Newman 1999	50 g/m2 (500 kg/ha) initial dose decreasing to 25 g/m2 (250 kg/ha) to maintenance dose of 10 g/m2 (100 kg/ha). More straw for muddy waters. Do not exceed 500 g/m2 (O2 depletion may occur). Uncertainty noted in applications to deep lakes and reservoirs.	Paper provides general guidance for use of barley straw and is based on his own and others' experiments (refs provided)./**1,3,4,5**
WDOE 2004	54 pounds/ac (60 kg/ha) low does to 225 lbs/ac (252.2 kg/ha) high dose.	Low values are for clear water; high values for muddy water. Based on Newman 2001 and Lembi 2002/**1,3,4,5**
Lembi 2001	225 lbs/ac (252.2 kg/ha); muddy lakes or lakes with severe algae growth may require 450-900 lbs/ac (not to exceed 900 lbs/ac), (504.4 – 1,008.8 kg/ha).	Based on her work and that of the Lake Water Quality Extension Program of the University of Nebraska/**1,3,4,5**

RELEVANCE OF THE BARLEY STRAW TREATMENT TO CYANOBACTERIA IN OREGON LAKES

It appears there is an increase in the incidence of Cyanobacteria blooms in Oregon based on reports issued by the Environmental Toxicity section of the Oregon Department of Human Services (http://oregon.gov/DHS/ph/envtox/maadvisories.shtml). It would appear reasonable, in view of the research performed and experience gained to date on field applications of barley straw to control algae, part of which work has been reviewed above (see abstracts of our literature review following paper references), to asses the feasibility of using barley straw in Oregon's waters of the state.

Is it reasonable, for example, to consider using some form of barley straw treatment to try to suppress the nuisance blooms of *Aphanizomenon flos-aquae* that regularly occur in Upper Klamath Lake (UKL) in south central Oregon? It may be significant that before the development of agriculture in the UKL watershed, the influence of wetlands on the water of UKL was much greater, and decomposition of wetland plants provided the main input of nutrients and organic matter to UKL. Recent UKL sediment coring studies show that AFA was not detectable in sediments deposited before about 1880, about the time human disturbances began, and that the abundance of AFA increased in step with conversion of wetlands to agriculture (see Geiger *et al.* 2005 for review of wetland loss and its consequences at UKL).

The available evidence suggests that barley straw mimics one or more of the properties of wetland effluents, particularly the phenolic materials that are responsible for the coloration of the "brown water" that flows from marshes. It may also be significant that streams draining from forests are often "tea colored" and have low algal abundances, and that leaf litter and rotted wood have been shown to release phenolic substances that suppress algal growth; the development of agriculture in the UKL watershed was accompanied by dramatic deforestation, which would have reduced the inflow of phenolics form this source as well.

EXPERIMENTAL VALIDATION OF THE BARLEY STRAW TREATMENT

Several unanswered questions remain about the mode of action of barley straw in suppressing algal growth, and in light of the uneven success of the method when tried in the USA, several kinds of experiments are called for, and we suggest these as top priorities:

1) *Laboratory experiments to assess the effects of barley straw treatment on* ***Aphanizomenon flos-aquae*** *from UKL.*

Although British studies have reported that growth of "*Aphanizomenon flos-aquae*" is effectively suppressed by barley straw in both laboratory (Martin & Ridge 1999) and field (Everall and Lees 1996) experiments, these studies did not specify whether the alga consisted of colonial (flake-forming, as in UKL) or solitary filaments. The name "*Aphanizomenon* *flos-aquae*" has commonly been applied to both forms, but recent molecular genetic studies (Li *et al.* 2000) showed that these two forms are in fact not closely related, so it cannot be safely assumed that these experimental results would apply to the UKL population. Cultures of *Aphanizomenon flos-aquae* from UKL as well as additional species of algae from UKL and other sources, using both UKL water and standard laboratory growth media, should be tested for susceptibility to suppression by barley straw.

2) *Investigation of the mode of action of barley straw treatment*

It is still unclear whether barley straw may interact significantly with nutrients (nitrogen and phosphorus) or metals, known to be chelated by plant exudates. The possibility exists that these essential substances are made unavailable to algae, even though conventional assays show that they are present at adequate concentrations and nitrogen and phosphorous supplementation fails to restore growth in barley straw-suppressed algae. It is also known that some chelators, but not others, cause metals such as iron and manganese to catalyze the Fenton reaction. This reaction breaks down hydrogen peroxide (which is produced by many algae under strong light and is also produced in the oxidative breakdown of plant phenolics) and releases hydroxyl radicals, which are by far the most damaging of all oxygen radicals. The Fenton reaction is also strongly stimulated by light, especially UV, which might be a particularly important factor at the 4,000 ft elevation of UKL.

The roles that bright light and UV light (i.e. sunlight) may play also remain to be investigated. Besides stimulating the Fenton reaction, light can be important in driving the breakdown and oxidation of plant phenolic compounds, which renders them highly active against algae. It is always recommended that barley straw be kept floating at the water surface to ensure anti-algal activity, and it is not clear whether this is merely to ensure aerobic conditions. One reason that even very high doses of straw cannot eliminate an algal bloom once it has begun may be that so little light penetrates the water column during a dense bloom that photochemical reactions in the water column are reduced dramatically.

SUGGESTED EXPERIMENTS:

Test for nutrient interactions by assaying barley straw-suppressed algae for nitrogen and phosphorous content. If these nutrients are deficient in these cells under high nutrient concentrations, it will be an indication that there are indeed nutrient interactions. Expose nutrient-replete algae to barley straw and observe whether cessation of growth is correlated with a decline in the nitrogen or phosphorous content of the cells, which would indicate interference with nutrient import mechanisms.

Investigate the role of light by preparing barley straw for treatments under various light conditions: darkness, visible light, and visible+UV, natural sunlight at UKL, and by exposing algae to barley straw under this range of conditions.

Investigate the role of oxidizing agents by comparing the effects of barley straw in the presence of added oxidizing agents and also reducing agents.

3) *Investigation of the significance of barley quality: cultivars and growing conditions.*

The widely-reported success with barley straw as an algae control measure in Britain contrasts with the mixed success reported in the USA. One possible cause of this discrepancy is differences in the barley varieties used or the conditions under which the crop is grown. One British report states that no differences were found in the effectiveness of straw from several different barley "varieties," or whether the straw was grown organically (Newman 1977 [IACR Web]). But anecdotal comments that British thatchers know that barley grown under high nitrogen yields a straw that is weak and rots quickly (suggesting low lignin content) are consistent with the well-known fact that heavy nitrogen fertilization causes rapid growth and weaker straw (low lignin). Lignin is thought to be one of the chief phenolics in barley, and it decomposes slowly, consistent with the months-long anti-algal effect that is commonly reported.

4) *Trials of other plant wastes for possible algistatic effects, e.g. ryegrass, conifer needles, bark dust, juniper waste*

Because other types of plant biomass besides barley straw (e.g. oak wood and leaves) have been shown to release algistatic substances, it would be worthwhile to assess the algistatic activity of other kinds of readily available plant biomass. In Oregon, great quantities of ryegrass straw are available, as well as conifer needles and bark dust from the forest products industry. The recent push to remove juniper from rangeland may present an opportunity to make this species easily available for use, should it prove effective.

5) *Field experiments*

Field experiments are also necessary, because the algistatic effects of barley straw seem to depend on conditions prevailing in the field, which may be difficult or impossible to replicate in the laboratory. Field experiments and are also the most likely to yield practical results, since the lessons learned from them can be applied directly to the *Aphanizomenon flos-aquae* bloom problem, or to lakes with dominance by other cyanobacteria.

The smallest-scale field experiments that are reasonably likely to replicate *Aphanizomenon flos-aquae* bloom conditions would be carried out in multi-hundred liter "limnocorral" enclosures suspended in the lake, so that the prevailing natural conditions (lakewater chemistry, temperature, sunlight) could be allowed to exert their effects (see Geiger *et al.* 2005 for a review of approaches made at UKL). These will test the effects of different doses of barley straw and types of water (open lake, wetland, river), and perhaps the effects of *Aphanizomenon flos-aquae* abundance and interactions of other algae and grazers in the presence of barley straw. This experimental approach also allows side-by-side comparison of "control" (no barley) treatments alongside barley experiments, as well as multiple replications of experiments, which cannot really be done with in-lake experiments not carried out in enclosures.

Ultimately, larger-scale experiments, probably first attempted in areas where localized effects could be most readily detected (e.g. smaller bays) will be necessary. Such experiments will not only establish whether algistatic effects can be demonstrated at this scale, but can also be used to work out the practical aspects of applying barley to treat large areas under the conditions prevailing in Upper Klamath Lake.

FEDERAL AND STATE AGENCY INTEREST IN BARLEY STRAW APPLICATIONS

Barley straw is not registered as a herbicide in either Washington or Oregon. In Washington State, as noted in Table 1, best management practices are provided for the application of straw in Washington water bodies. The agency in Oregon responsible for managing herbicide use in the state is the Department of Agriculture (http://oregon.gov/ODA/PEST/). Barley straw, to date, can not accurately be called a 'herbicide'. It has been demonstrated to be an 'algistat' with certain algae, but may damage algae through compounds produced by straw decomposition in relation to UV light and associated chemical reactions. How to secure approval for the use of barley straw specifically for suppression of algae growth has been a puzzle both for agency staff and for those interested in applying barley in waters of the state. Yet barley straw is available from many sources as a means of 'clarifying the water'.

Other agencies such as the Department of Environmental Quality have an interest in material such as straw that when applied improperly could affect water quality (e.g. reduced dissolved oxygen, increased turbidity, debris, etc.). Agencies such as the Oregon Department of Fish and Wildlife may have an interest in questions of effects of straw applications on aquatic habitats. Federal and State agencies such as the Corps of Engineers and the Oregon Marine Board would have an interest in the application of straw with respect to interference with boating. The Corps of Engineers and the Oregon Division of State Lands (owner of much of the bottom of many lakes in the state) may have an interest in barley straw applications as related to wetland fill laws (putting organic material in waters of the state). This brief review of potential agency interest suggests the range challenges that need to be addressed as work on barley proceeds from the laboratory or greenhouse to contained field assays (limnocorrals) to pond and whole lake applications.

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ABSTRACTS OF LITERATURE ON BARLEY STRAW-ALGAE CONTROL

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Anhorn, Randall J. 2005. A study of the water quality of 145 Metropolitan area lakes. Metropolitan Council, Meares Park Center, 230 East Fifth Street, St. Paul, Minnesota. Publication Number 32-04-015. June 2005.

The report reviews the results of monitoring 145 lakes in the vicinity of Minneapolis and St. Paul, Minnesota in 2004. Information is provided on the relative water quality condition of these lakes. Five of the lakes with degraded water quality were chosen for barley straw treatments. Among these lakes Valley Lake was chosen for more detailed analysis of the effects of straw applications, including a chemical analysis of the water for compounds associated with straw. The straw application in Valley Lake has been monitored since 1999. The water quality of the lake, including algae, had been monitored 1995-1997. There was a noticeable reduction in algae growth in 1999-2002, and a gradual degrading of water quality conditions 2003 and 2004. Degraded water quality during the continued application of barley is ascribed to escalating growth of panfish populations (~30x pre-barley straw condition). Valley Lake water was analyzed for a breakdown of phenol concentrations as part of 57 base neutral acids and organic compounds (BNA's) following barley straw applications. No phenols were detected. An alternative hypothesis was therefore proposed. Barley straw provides a carbon source for carbon-limited microbial growth. With the carbon availability secure, the microbial community production soars and phosphorus uptake is shunted through the microbial loop ecosystem. The presence of decaying barley straw therefore results in phosphorus limitation for algae, not inhbitition by a released chemical compound.

Ball, Andrew S., Matthew Williams, David Vincent, and James Robinson. 2001
Algal growth control by a **barley** straw extract.
Bioresource Technology. 77(2): 177-181.
In recent years, there has been an apparent increase in the occurrence of harmful algal blooms occurring in potable waters. The potential of a simple **barley** straw extract to inhibit algal growth was assessed. Algal growth in lakewater was inhibited by the addition of **barley** straw (1% w/v), with the chlorophyll alpha concentration remaining below the original level (40 mug 1-1) throughout the experiment. In contrast, in the presence of wheat straw, algal biomass increased, reaching a final chlorophyll a concentration of 1160 mug 1-1 after 28 days. Analysis of the remaining particulate straw at the end of the experiment showed that the lignin content of **barley** straw had increased significantly from 10-33% (w/w). Further, a preparation of a simple aqueous extract from the decomposed-**barley** straw was found to inhibit the cyanobacteria *Microcystis sp.* and the algal species *Scenedesmus*, with chlorophyll a levels some 10-fold lower than in untreated flasks. This study shows that a decomposed-**barley** extract, even in a very dilute concentration (0.005%) was capable of inhibiting the growth of *Microcystis* sp., a commonly occurring cyanobacterium which produces the toxin microcystin and has been responsible for some of the most serious pernicious algal blooms in the UK.

Barrett, P.R.F., J. W. Littlejohn, and J. Curnow. 1999
Long-term algal control in a reservoir using **barley** straw.
Hydrobiologia. (415): 309-313.
Populations of cyanobacteria, diatoms and unicellular green algae in a potable supply reservoir have been suppressed continuously since 1993 by repeated treatments of **barley** straw. Algal cell numbers dropped soon after the straw was introduced and have remained at approximately one quarter of those recorded prior to treatment. All types of algae, including diatoms and cyanobacteria, have been uniformly affected and no

new or resistant species have developed. Taint and odour problems in the potable water have been reduced and filters at the water treatment works require less frequent cleaning.

Barrett, P. R. F., J. C. Curnow, and J. W. Littlejohn. 1996
The control of diatom and cyanobacterial blooms in reservoirs using barley straw
Hydrobiologia, 340(1-3):307-311
A potable supply reservoir, with a long history of diatom blooms in spring and cyanobacterial blooms in summer, was treated with barley straw in March 1993 with subsequent additions in December 1993 and June 1994. Within two months of the initial treatment, algal numbers started to fall compared with previous years and have remained consistently lower throughout 1993 and 1994. Cyanobacteria have not bloomed and cell numbers remained low. Chemical analysis of the water showed locally elevated concentrations of geosmin close to the straw on one occasion but the overall concentration of this and a range of other organic molecules remained within acceptable limits and at concentrations similar to those found in other untreated reservoirs in the region. Observed and potential advantages to public health and potable supply management resulting from the use of barley straw are discussed.

Boylan, J. D. and J. E. Morris. 2003
Limited effects of barley straw on algae and zooplankton in a midwestern pond
LAKE AND RESERVOIR MANAGEMENT 19 (3): 265-271
Researchers in the United Kingdom have reported that barley straw can be used to control a variety of planktonic algae, as well as the filamentous alga Cladophora spp. This method appears to be cost-effective, user-friendly, and environmentally sound. If these results could be obtained in the United States, using barley straw would be a good alternative to using copper sulfate. However, research has shown that barley straw must be subjected to well-oxygenated water for it to become anti-algal. Consequently, the sites of most studies conducted in the UK in which barley straw showed an effect have been somewhat lotic. Midwestern ponds are typically stagnant, and often become oxygen-poor during summer months, and therefore it is questionable whether barley straw would work. W e attempted to control algae (filamentous and planktonic) growing in replicated limnocorrals that were built inside of a 1-ha pond; limnocorrals were stocked with three levels of barley straw. In addition, we tested whether the straw had effects on zooplankton community structure. No consistent degree of algal growth inhibition was observed for either alga type, and zooplankton community structure was not affected throughout this 14-week study ($P < 0.10$). Our results, as well as those of some other US researchers, may be partly explained by inadequate levels of oxygen within the decomposing straw caused by a lack of water exchange between the interstices of the straw and the water body.

Brownlee, E. F. S. G. Sellner and K. G. Sellner. 2003
Effects of barley straw (*Hordeum vulgare*) on freshwater and brackish phytoplankton and cyanobacteria
Journal of Applied Phycology [J. Appl. Phycol.]. 15(6):525-531.
A short-term laboratory study was conducted to investigate the effect of barley straw in controlling several common phytoplankton and cyanobacterial species. Following a one-month incubation of barley straw in coarsely filtered fresh Potomac River and brackish Patuxent River waters, the growth of six autotrophic taxa was followed in culture. Barley straw slurry reduced the yield of three taxa (*Ankistrodesmus falcatus, Chlorella capsulata, Isochrysis sp*.) in comparison with cultures not receiving the slurry. Although no significant changes in growth were detected with three other taxa (*Cyclotella sp., Prorocentrum minimum, freshwater Pseudanabaena sp*.), some patterns indicated potential impacts of the barley straw. First, a higher addition of straw to *Cyclotella* sp. resulted in a lower biomass accumulation than in cultures receiving lower levels. Second, the bloom-forming dinoflagellate *Prorcentrum* minimum was apparently stimulated at low barley straw levels, perhaps suggesting conditions associated with the straw (metals-chelation, bacterial-produced nutrients) might stimulate dinoflagellate growth. Third, species shifts were observed in two of the cultures, with barley straw favoring shifts from *Isochrysis to a Cyclotella* sp. - *Thalassiosira* sp. mixture and shifts from *Pseudanabaena to a Pseudanabaena - Scenedesmus* mixture. These results provide new records for the susceptibility of freshwater and brackish phytoplankton taxa to

barley straw exposure, including species-specific responses and shifts in species dominance in mixed assemblages.

Butler, B., D. Terlizzi, and D. Ferrier. 2001
Barley straw: a potential method of algae control in ponds.
Maryland Sea Grant
Contact the originating Sea Grant program for ordering information: http://nsgl.gso.uri.edu/ordering.htm.
Also available on loan from the Sea Grant Library (NSGL): http://nsgl.gso.uri.edu.
The use of barley straw to control algal growth in freshwater systems is a fairly new development. This fact sheet briefly describes the nature of algal problems in Maryland and strategies for controlling them. Barley straw is highlighted as inexpensive, not harmful and even beneficial to other aquatic organisms.

Caffrey, J. M. and C. Monahan. 1999
Filamentous algal control using **barley** straw.
Hydrobiologia. (415): 315-318.
Year-round problems with dense growths of filamentous algae reduce the amenity and conservation value of Irish canals. Because algal control operations were relatively ineffective, trials using **barley** straw were undertaken. These commenced in October 1990 on a section of the Royal Canal where filamentous algae continuously interfered with amenity exploitation and water management. Bales of **barley** straw were anchored along the canal banks at roughly 50 m intervals. Further straw applications were made in 1991 and 1992. Algal growth in the control section broadly followed a cyclical pattern, with peak biomass between July and September and low production in February and March. In the treated section, however, algal biomass decreased from the time the straw was first introduced. Thereafter, as long as rotted straw was present, no filamentous algae were recorded. The absence of algae in this section between August 1991 and spring/summer 1993 permitted the recolonisation of higher plants, which are commonly less troublesome and more ecologically useful than algae.

Choe, S. and I. H. Jung. 2002
Growth inhibition of freshwater algae by ester compounds released from rotted plants
JOURNAL OF INDUSTRIAL AND ENGINEERING CHEMISTRY 8 (4): 297-304 **NOT AT OSU**
The amount of usable clean water is decreasing due to urbanization, industrialization, and algal blooming. Therefore, experiments were carried out to determine the growth inhibition of freshwater algae by decomposed material of plants and to identify the inhibitory chemicals. It was found that mugwort was the most effective in inhibiting algal growth. The inhibitory chemicals, released from the rotted plants - mugwort, barley straw, rice straw, and chrysanthemum, were identified as hexanedioic acid, a dioctyl ester and 1,2-benzenedicaboxylic acid, a bis (2-ethylhexyl) ester by GC/MSD. The ester compounds were found to be the major antialgal chemicals, while a phenol compound was identified as a subagent. In the presence of the phenol compound, the ester compounds appeared to have a stronger effect on the algal-growth inhibition, and these compounds were produced as allelochemicals to algal growth.

Cooper, Jerry A., Judith Pillinger and Irene Ridge. 1997
Barley straw inhibits growth of some aquatic saprolegniaceous fungi.
Aquaculture. 156(1-2): 157-163.
Barley straw rotting in water under aerobic conditions controls the growth of both algal and cyanobacterial species and is exploited as a method to control nuisance algae. We report here the effect of anti-algal **straw** on isolates of an aquatic fungus that comprises a significant component of the freshwater aquatic ecosystem and causes a major fungal disease in fish and other aquatic animals. In a laboratory bioassay, **straw**, at dose rates comparable to those which inhibit algal growth, stopped the mycelial growth of isolates of two species of *Saprolegnia, S. parasitica* and *S. diclina; S. ferax* was less inhibited. Inhibition in the laboratory bioassay was also recorded at the lower dose rate at which **straw** is widely used in environmental algal control programmes. We suggest that **straw** may ameliorate symptoms of saprolegniasis in fish, but it is not clear whether **straw** can prevent the rapid spread of the fungus in hatcheries.

Duh Pin-Der. Yen Gow-Chin,.Yen Wen-Jye, and Chang Lee-Wen. 2001
Antioxidant effects of water extracts from **barley** (*Hordeum vulgare* L.) prepared under different roasting temperatures.
Journal of Agricultural & Food Chemistry. 49(3): 1455-1463.
The antioxidant effects of water extracts of roasted **barley** (WERB) were investigated under different roasting temperatures and compared with those of the water extracts of unroasted **barley** (WEUB). It was found that the Maillard reaction products increased upon increasing the roasting temperatures. Both WERB and WEUB exhibited significant antioxidant activities in linoleic acid and liposome model systems. Although WERB and WEUB afforded considerable protection against the damage of deoxyribose and proteins, the antioxidant efficiency of roasted samples was weaker than that of unroasted samples because of the reduction of antioxidant components (catechin, tocopherol, and lutein) with increasing roasting temperature. Unroasted samples were more effective in reducing power, quenching free radical, hydroxyl radical, and chelating **iron** than the roasted samples. The different antioxidant activity among roasted and unroasted **barley** samples may be partly attributed to the changes in catechin, tocopherol, and lutein contents.

Everall, N. C. and D. R. Lees. 1997
The identification and significance of chemicals released from decomposing **barley** straw during reservoir algal control.
Water Research. 31(3):614-620.
The presence of decomposing **barley** straw at c. 25 g m-3 in a disused water supply reservoir significantly reduced cyanobacterial and general phytoplankton activity compared with a control water body. Algal control was simultaneous with the release of a "cocktail" of phytotoxic chemicals, following both the initial immersion of the straw and then after a c. 3 month period of degradation in water. The toxicity of straw leachate to phytoplankton could be explained by the presence of toxicologically relevant levels of phenols and oxidized phenolics. Optimization of the control of phytoplankton using **barley** straw is discussed with respect to observed environmental physicochemical conditions shown to favor the production of the more toxic oxidized phenoics under field conditions.

Friedman, Robert S. [**Inventor**, Reprint author]. 2000
Green water inhibitor-GWI
Official Gazette of the United States Patent & Trademark Office **Patents**. 1240(3). Nov. 21, 2000.
A composition for effective algae control comprising bacteria and humic acid made by extracting the liquid from barley straw soaked in water for a period of time.
Claims
1. A composition comprising humic acid and bacteria in about 25 gallons of water made by the process comprising soaking about 5 pounds of barley straw in about 25 gallons of water for about 48 hours and extracting the resulting liquid from the straw.
2. A process for making a composition comprising humic acid and bacteria comprising the a first step of soaking about 5 pounds of barley straw in about 25 gallons of water for about 48 hours and a second step of extracting the resultant liquid from the straw.
Description
PRIOR ART
Two British scientists discovered that barley straw was an effective algae control. They recommended placing a bale in a half acre of water in fish farms. This process involves hauling cumbersome bales to farms, tethering them to heavy weights, and waiting six to eight weeks for secretions to seep into the water. Some parts of the USA don't grow barley straw nor do some foreign countries.
My GWI process brings much quicker and more positive results with less inconvenience and costs. Packaged in quarts, gallons and 55-gallon drums. My GWI process makes the finished ready-to-use product available to the hobbyist, aquaculturists, lake and reservoir owners, eliminating the need to buy straw bales.

It can readily be seen that time, convenience and economy will be the benifits of my processing and distributing invention, "GWI" Green Water Inhibitor.

Methods of application: Spraying from a boat or the banks of lakes. Airplane spraying of large lakes.

Results are evident in some cases, within hours and other situations, one to four days.

The straw bales require weeks before results are evident.

If there is no moving current or water turbulence, the straw bales can not disperse enough of their secretions to accomplish their algae control for very long periods as more algae is being generated daily.

Thus it can be readily seen that the efficacy, convenience and economy lies in the utilization of my invention as opposed to the methodology recommended by the scientists. One aspect of the invention is a composition comprising humic acid and bacteria in 25 gallons of water made by a process comprising soaking 5 pounds of barley straw in 25 gallons of water for 48 hours and extracting the resulting liquid from the straw.

The process can further include adding heat and oxygen to the mixture of barley straw and water. The process can optionally further include the addition of dried select microbial species to the resulting liquid to enhance the viability of the product and increase the bacterial population. The time required to soak the barley straw can vary, as can the quantity of water that it is soaked in. None of the embodiments of the invention are necessarily limited to the amounts described herein.

Gibson, M. T., I. M. Welch, P. R. F. Barrett, and I. Ridge . 1990

Barley straw as an inhibitor of algal growth. 2. Laboratory studies.

Journal of Applied Phycology [J. APPL. PHYCOL.], 2(3):241-248.

The presence of rotting **barley** straw in water inhibited the growth of several planktonic and filamentous algae in laboratory culture. The inhibitory effect was produced progressively during decomposition of the straw at 20 degree C and reached a maximum after six months. When the straw was autoclaved, all inhibitory activity was lost. Algae recovered and continued to grow normally when transferred from cultures containing rotting straw to sterile culture medium. Addition of liquor from rotting straw also inhibited algal growth. The capacity to inhibit growth remained in the liquor after passage through a 0.2 mu m filter but was removed by activated carbon. The inhibitory effect of straw shows promise as a practical means of limiting the growth of a range of algae which can cause problems in aquatic systems.

Harriman, R., E. A. Adamson, R. G. J. Shelton, and G. Moffett. 1997

An assessment of the effectiveness of straw as an algal inhibitor in an upland Scottish loch

Biocontrol Science and Technology [Biocontrol Sci. Technol.], 7(2): 287-296

The control of algal blooms caused by a colony of black-headed gulls in an upland loch in central Scotland was attempted using bales of **barley** straw. The initial evidence suggests that the release of the inhibitory substance commenced 6-10 months after placement of the bales and was sustained for at least 18 months. The moored bales provided a useful substrate for benthic invertebrates, acting as a shelter and detritus trap. Algal diversity appeared not to be affected by the bales, but the cell numbers of the main species were affected.

Holz, J. C. C. J. Fessler, A. A. Severn, and K. D. Hoagland. 2001

Effects of barley straw extract on growth of five species of planktonic algae

Journal of Phycology [J. Phycol.], 37(s3):**24-25**

The effects of exposure to barley straw extract and the timing of exposure on the growth of four common cyanophyte species and one species of green algae were investigated in two laboratory experiments. Clonal cultures of *Anabaena cylindrica, Cylindrospermum sp., Gloeocapsa sp., Eucapsis sp., and Chlorella vulgaris* were obtained from culture collections. In both experiments, the algae were cultured in Guillard's WC medium at 20 degree C on a 12:12 L/D photoperiod. In the first experiment, the algae were dosed with four concentrations of barley straw extract at the beginning of the experiment (day 0) and growth was monitored every second day using fluorometric detection of chlorophyll a for 14 d. In the second experiment, the algae were dosed with the same extract concentrations, but the extract was not added until the algae were in exponential growth phase (day 6). Both experiments also had control treatments (i.e. no extract) and each extract and control treatment was replicated five times. Growth of *C. vulgaris* was inhibited by all doses in both experiments, but inhibition was 22% greater when the extract was added on day 0. Growth of *Gleocapsa* sp. was slightly inhibited by all doses when the extract was added on day 0, but not when it was added on day 6. No other species were inhibited, regardless of dose or timing of dose. The results of this study and other bioassay studies suggest that differential susceptibility to barley straw among algae is common and may reduce the effectiveness of barley straw as an algal control technique.

Knauer, Katja and Jacques Buffle. 2001.
Adsorption of fulvic acid on algal surfaces and its effect on carbon uptake.
Journal of Phycology. 37(1):47-51.
Adsorption of Suwannee River fulvic acid (SRFA) to algal surfaces of three green algae was studied at environmentally relevant pH values (4-7) and SRFA concentrations (5-100 mgcntdotL-1). The influence of adsorbed SRFA on carbon uptake of Scenedesmus subspicatus Chodat was also examined. Although no adsorption was observed at neutral pH values (pH 6 and 7), at pH 4 up to 31 mg SRFAcntdotm-2 and at pH 5 up to 4 mg SRFAcntdotm-2 was adsorbed to the algal surfaces. Electrophoretic mobility measurements of S. subspicatus demonstrated an increase in the negative surface charge of the alga in the presence of SRFA at pH 4. The adsorbed SRFA also influenced 14C uptake in S. subspicatus; in this case, enhanced carbon uptake could be related to the amount of adsorbed SRFA. The binding of humic substances by algal surfaces was interpreted as the result of hydrogen bonding and hydrophobic interactions.

Lembi, Carole. A. 2001
Aquatic plant management: Barley straw for algae control
Botany and Plant Pathology Department, Purdue University
lembi@btny.purdue.edu
Lembi article: www.btny.purdue.edu/Pubs/APM/APM-1-W.pdf
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E-mail: steve.enger@dnr.state.mn.us and dave.wright@dnr.state.mn.us

Martin, D. and I. Ridge. 1999
The relative sensitivity of algae to decomposing **barley straw**
Journal of Applied Phycology [J. Appl. Phycol.], 11(3):285-291
Decomposing barley straw has previously been shown to inhibit the growth of a limited number of algae under both laboratory and field conditions. Bioassays were conducted on a range of algae to evaluate their relative sensitivities to straw-derived inhibitor(s). A range of sensitivities was found, including some species that were resistant to the straw-derived inhibitor(s). A microcystin-producing strain of *Microcystis aeruginosa* was very susceptible to decomposing **barley** straw. Bioassays using *Euglena gracilis* suggest that the inhibitory compounds are not derived from the phototransformation of straw decomposition products and do not act primarily by inhibiting photosynthesis. Susceptibility to **barley** straw appears not to be related to general taxonomic or structural features. Possible implications for algal populations in natural freshwaters are briefly discussed.

Molversmyr, A. 2002
Some effects of rotting straw on algae
Congress in Dublin 1998.

Williams, WD (ed) . Proceedings. 27(7):4087-4092. Verhandlungen. Internationale Vereinigung fur theoretische und angewandte Limnologie/Proceedings. International Association of Theoretical and Applied Limnology/Travaux. Association internationale de Limnologie theorique et appliquee [Verh. Int. Ver. Theor. Angew. Limnol./Proc. Int. Assoc. Theor. Appl. Limnol./Trav. Assoc. Int. Limnol. Theor. Appl.]. 2002.
The eutrophic lakes in the agricultural area of south-western Norway are typically soft-water lakes with dense populations of planktonic diatoms in the spring, and blooms of various planktonic cyanobacteria in late summer (usually the genera Anabaena, *Aphanizomenon* and Microcystis) that on occasions produce toxins. The total phosphorus content of the lake water is, on average, typically in the range of 20-50 mu g P/L, and the amount of phosphate (as soluble reactive phosphorus, SRP) is usually below the limit of quantification (<2 mu g P/L) Some local interest has been taken in the possible use of straw to control blooms of cyanobacteria in these lakes. The lakes and reservoirs where barley straw has been used to control algal growth have, in contrast, had much higher levels of nutrients when such data have been reported (Welch et al. 1990, Everall and Lees 1996), with phosphate (SRP) at levels that may not be limiting for algal growth (20-100 mu g P/L or higher). This paper reports the results of laboratory studies designed to investigate into the possibility of using straw to control blooms of cyanobacteria in local eutrophic lakes.

Newman, Jonathan R. and P. R. F. Barrett. 1993
Control of *Microcystis aeruginosa* by decomposing **barley** straw.
Journal of Aquatic Plant Management. 31(JAN. SPEC. ED.):203-206.
Growth of the blue-green alga Microcystis aeruginosa is inhibited by the presence of decomposing **barley** straw in laboratory culture to levels of 6% of that achieved in control experiments. The effect appears to be algistatic rather than algicidal. Final biomass in regrowth experiments is independent of previous treatment. Values for regrowth from control treatments (2.96.10-6 cells cm-3) were not significantly different from values for regrowth of cells from the most inhibitory treatment (2.67.10-6 cells cm-3). Cells inhibited by exposure to straw recovered, achieving the same growth rate as untreated cells when reinoculated into straw-free media. Growth inhibition of 95% can be achieved with 2.57 g straw (dry weight) m-3 water. These results are compared to the results of a survey in Great Britain and Ireland on the use of straw to control algae. Decomposing **barley** straw inhibits the growth of both filamentous and blue-green algal species in all types of water bodies so far assessed. Possible causes of the inhibitory effect are discussed.

Nicholls, K. H., R. G. Taylor, R. W. Bachmann, J. R. Jones, R. H. Peters, and D. M. Soballe, DM (eds). 1995
Experimental use of **barley** straw for algae control in Ontario ponds
15. Annual International Symposium of the North American Lake Management Society, Toronto, ON (Canada), 6-11 Nov 1995
Lake and Reservoir Management [LAKE RESERV. MANAGE.], 11(2):175, 1995
NT: Notes **Summary only.**
In response to published reports from England on the successful control of algae growth by decomposing **barley** straw in surface waters and laboratory experiments, 18 southern Ontario ponds were selected for experimental additions of **barley** straw over the period 1991-1995. All ponds were evaluated (chlorophyll a, phytoplankton, major nutrients and ions) biweekly between June and September of all years. Treatment years were 1992, 1993 and 1995 and treatments included three different doses of dry straw (25, 65 and 180 g/m super(3)). Controls included untreated ponds (all 5 years) and other ponds with from 1-4 years of background (untreated) data prior to straw additions. The algae control effect apparently resulted from the production of algistatic agents by fungi and other aquatic protista colonizing the straw during the early stages of its decomposition. No marked changes or differences relative to control ponds in nutrients could

account for the declines in algae which were manifested in the main response variables (chlorophyll a, turbidity and phytoplankton biovolume). Mean and median chlorophyll-to-total phosphorus ratios in samples from treated ponds were about 2x greater than those from untreated ponds. Although the percentage change in response variables after 1991 in untreated ponds was often negative because of year-to-year differences in weather, decreases in the response variables were 2-5x greater in ponds treated with straw. All major classes of algae were affected. The application of straw to ponds for the control of excessive algae growth is a less expensive, simpler and more "environmentally friendly" alternative to conventional chemical treatment.

O'Donnell, J. and T. E. Murray. 2000
Use of barley straw as an algicide in lake management. [Meeting] Journal of the Pennsylvania Academy of Science. [print] 73(Suppl.):172.

Pillinger, .J. M., J. A. Cooper, and C. J. Harding. 1996
Stable free radical from plant litter decomposing in water
JOURNAL OF CHEMICAL ECOLOGY 22 (5): 1001-1011
The presence of a stable radical species in both fresh straw and that which had been submerged in aerated water for up to six months has been demonstrated using electron paramagnetic (spin) resonance (EPR or ESR) spectroscopy. A radical signal was associated also with material shown to contain straw lignin markers, which was leached from the rotting straw into surrounding water. Fresh straw treated with strong alkali to remove phenolics did not show a radical signal. The possible effect of a dissolved stable free radical is discussed in relation to the antagonistic effect of rotting straw on algal and cyanobacterial growth in water to which straw has been added as a nuisance algal control agent.

Pillinger, J., J. A. Cooper J. A. and I. Ridge. 1994
Role of phenolic compounds in the antialgal activity of **barley** straw.
Journal of Chemical Ecology. 20(7):1557-1569.
Barley straw decomposing in well-aerated water releases a substance(s) that inhibits algal growth. Phenolic compounds are toxic to algae but are unlikely to be present in sufficient quantities to account for the extended antialgal action of straw. However, straw is antialgal under conditions that may promote oxidation of phenolic hydroxyl groups to quinones; tannins are antialgal under similar conditions. The toxicity of authentic quinones towards Microcystis is confirmed; the quinones are some 10-3 times more antialgal than phenolic acids. The possibility that oxidized lignin derivatives may be involved in straw toxicity towards algae is discussed.

Pillinger, J. M., I. Gilmour, and I. Ridge. 1995
Comparison of antialgal activity of brown-rotted and white-rotted wood and in situ analysis of lignin.
Journal of Chemical Ecology. 21(8):1113-1125.
Brown-rotted wood has been used as a source of lignin to investigate further the antialgal effects of lignocellulosic materials such as decomposing **barley** straw. The antialgal activity of brown-rotted and white-rotted wood has been determined in a laboratory bioassay. Using pyrolysis gas chromatography-mass spectrometry, the lignin of the rotted wood samples has been compared and the significance of the structure of the lignin in antialgal activity is discussed.

Ridge, Irene and J. M. Pillinger. 1996
Towards understanding the nature of algal inhibitors from **barley** straw.
Hydrobiologia. 340(1-3):301-305.
The algal inhibitors released from **barley** straw decomposing in water and providing the basis for its use in algal control could be either of microbial origin or derived from straw components. We report here that unrotted straw releases algal inhibitors if finely chopped or autoclaved, providing further support for the

view that straw, and not microbial colonists, is the primary source of inhibitors. Further support is also provided for the suggestion that inhibitors are or derive from oxidized lignin. Comparisons of lignin-enriched wood (brown-rotted) with lignin-depleted wood (white-rotted) from various deciduous trees show high antialgal activity of the former and little or no activity of the latter. Preliminary studies have shown that solubilized lignin is present in the liquor from rotted **barley** straw and brown-rotted wood. Since, however, the antialgal effects of deciduous leaf litter appear to depend initially on release of tannins and given that alkaline, oxidizing conditions are usually essential for antialgal activity, it is proposed that oxidized polyphenolics, derived from lignin or tannins, are a source of algal inhibitors from plant litter.

Ridge, I. J. Walters, and M. Street. 1999
Algal growth control by terrestrial leaf litter: a realistic tool?
Hydrobiologia, vol. 395/396:173-180
When **barley** straw and deciduous leaf litter decompose aerobically in water, inhibitors are released that suppress the growth of nuisance algae. **Barley** straw has been widely used for algal control in small, shallow lakes and we review the advantages and disadvantages of the method. It is particularly effective at promoting the switch from algal to macrophyte domination. Despite its cheapness and apparent safety in the short term, however, the use of **barley** straw requires considerable management effort and the long-term ecological safety of such un-natural litter inputs is unkown. We therefore recommend it to lake managers primarily as a short-term measure. Deciduous leaf litter from a range of woody species can suppress the growth of *Chlorella* and *Microcystis* very effectively in laboratory bioassays and, in field trials with medium-sized ponds, the addition of leaf litter produced significant inhibition of the filamentous alga *Cladophora glomerata*. We followed the development of algal inhibitory activity over 2.5 years with freshly fallen oak leaves placed in a large tank of aerated water and using *Chlorella* as the test species. Two periods of inhibitor release were identified: 4-90 days (early phase) when soluble, relatively stable inhibitors were present in tank liquor, probably generated from oxidized tannins; and 120-900+ days (late phase) when inhibitors were relatively unstable in solution and were associated primarily with fine particulate organic matter (FPOM). Late phase inhibitors may, as suggested for **barley** straw, be generated during the oxidative breakdown of lignin. The prolonged and powerful anti-algal properties of these natual litter inputs offer possibilities for low-effort, sustainable management of lakes and catchments so as to reduce the problem excessive algal growth.

Stewart, D., H. M. Wilson, P. J. Hendra, and I. M. Morrison. 1995
Fourier-transform infrared and Raman spectroscopic study of biochemical and chemical treatments of oak wood (*Quercus rubra*) and **barley** (*Hordeum vulgare*) straw.
Journal of Agricultural & Food Chemistry. 43(8):2219-2225.
FT-IR and Raman spectroscopes were used to investigate the changes in composition and structure of oak wood and **barley** straw that had been subject to chemical and biochemical treatments. The samples were also analyzed gravimetrically for residual neutral sugar composition and lignin and uronic acid content. The spectroscopic techniques provided complementary information. Changes in the relative proportions of crystalline and amorphous cellulose accompanying biochemical treatment were best reflected in the Raman and DRIFT spectra, respectively. Delignification of both tissues produces bands in the Raman spectra consistent with the lignin oxidation. Treatment of both types of raw material with aqueous acid produced highly colored residues resulting in Raman spectra of limited use due to problems with fluorescence. However, the DRIFT spectra of these tissues did not suffer this problem and provided information on the behavior of lignin (hydrolysis and repolymerization) and the noncellulosic polysaccharides (hydrolysis) in acid conditions. The decreased fluorescence in the Raman spectra of **barley** straw after alkali extraction is suggested to be due to the removal of the covalently bound cinnamic acids.

Terlizzi, Daniel E. [Author, Reprint Author; E-mail: dt37@umail.umd.edu]; Ferrier, M. Drew [Author]; Armbrester, Erin A. [Author]; Anlauf, Kara A. [Author]. 2002
Inhibition of dinoflagellate growth by extracts of barley straw (*Hordeum vulgare*).
Journal of Applied Phycology. 14(4):275-280.

Growth of dinoflagellates representing three orders, the Gymnodiniales, Peridiniales, and the Prorocentrales was examined following treatment with barley straw extract. Selected dinoflagellate taxa showed growth responses similar to those reported for freshwater algae including: inhibition (*Gyrodinium galatheanum, Gymnodinium sanguineum, Heterocapsa triquetra and H. pygmaea*); stimulation (Gyrodinium instriatum, Prorocentrum minimum and P. micans); and no effect (*Gyrodinium estuariale, G. uncatenum, Ceratium furca, Peridinium* sp.). Although barley straw extracts do not appear to have value as a universal management tool for dinoflagellates, they may have potential in management of specific taxa and possibly taxonomic groups.

Welch, I. M. P. R. F. Barrett, M. T. Gibson, and I. Ridge. 1990
Barley straw as an inhibitor of algal growth 1: Studies in the Chesterfield Canal.
Journal of Applied Phycology [J. APPL. PHYCOL.], 2(3):231-239
The presence of rotting barley straw in a disused canal reduced the amount of filamentous algae. No effect on algae was observed during the first season after the introduction of straw but algae were decreased in three subsequent years. Algal growth on microscope slides suspended in the water downstream of the straw was reduced by 90%, compared with slides upstream of the straw. A similar result was obtained for *Cladophora glomerata* grown in chambers in the canal. Phosphate, nitrate and ammonium concentrations were not altered significantly by the presence of straw, but ****nitrite concentrations were increased during summer months.**** Neither the nitric increase, nor the possibility of pesticides being washed off the straw were considered likely causes of algal growth inhibition.

Wisniewski, R.. 2002
Attempts to eliminate cyanobacterial blooms in Lake Leasinskie
Environment Protection Engineering [Environ. Prot. Eng.]. 1:15-26..
In the years 1998-2001, investigations of Leasinskie Malee and Zamkowe Lakes were conducted. The two lakes are shallow and very susceptible to degradation. Very high trophic level, high pollution level and recurring annual cyanobacterial blooms have caused that lakes have not been recreationally used since 1994. The aim of investigations was to work out the programme of reservoirs restoration. In order to test the methods, in June 1998 trials of cyanobacterial bloom inhibition in natural, isolated bath area were undertaken. Main measures were exposure of barley straw bales and addition of FeCl sub(3). After one month considerable changes in the composition of phytoplankton were recorded. The drastic slump in the biomass of ***Aphanizomenon flos-aquae*** and domination of eucariotic algae were observed. Water transparency substantially increased. The measures were repeated and the method was modified and developed in the successive years. The main causes of temporarily worse effects were damage of isolating barriers in the bathing area and seasonal increase in BOD sub(5) caused by influx of fine-grained organic suspension from unidentified source.

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Barley straw for algae conrol.
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