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LONG TERM EVALUATION OF REDUCED CHEMICAL PESTICIDE MANAGEMENT OF GOLF COURSE PUTTING TURF

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ABSTRACT

Global concerns for environmental quality have resulted in a proliferation of fertilizer and pesticide regulations that restrict golf course management programs. The objective of this project was to investigate the long-term effects of conventional and alternative cultural and pest management programs, designed to reduce reliance on chemical pesticides, on the quality and performance of golf putting surfaces. A seven-year study was conducted on the putting surfaces at the Bethpage State Park Green Course, Farmingdale, NY, USA comparing conventional pest management (CPM), integrated pest management (IPM) and biologically-based pest management (BBPM) under conventional cultural (CC) and alternative cultural (AC) management. A pesticide risk indicator model, the Environmental Impact Quotient (EIQ) was used to assess environmental risk. CPM provided the highest quality turf independent of cultural management, however IPM programs resulted in acceptable turfgrass quality throughout the study. AC systems required significantly greater labor resources and over time IPM program became the least labor-intensive pest management system. The environmental impact as measured by a pesticide risk indicator model of the pesticides used in the IPM and BBPM programs was reduced between 50 and 95 percent compared to CPM programs. Golfer satisfaction surveys indicated the putting surfaces provided acceptable visual quality and adequate ball roll. This study represents the first long-term management system based project conducted in the golf turf industry and suggests that a properly implemented IPM program under conventional culture can meet golfer demand, reduce labor resources, provide acceptable quality and significantly reduce environmental risk as measured by a pesticide risk indicator model.

Keywords: annual bluegrass, management system research, biological control, integrated pest management, pesticides, turfgrass disease

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INTRODUCTION

Global concerns for human health and environmental quality have resulted in a proliferation of fertilizer and pesticide regulations that restrict golf course management programs (Racke, 2000). The utilization of philosophies such as the "Precautionary Principle" in development of European Union regulation is establishing an international model (Fisher et al., 2006) motivating leading golf governing bodies such as the Royal and Ancient (R&A) to adopt sustainable course management philosophies and the United States Golf Association (USGA) to invest millions of dollars in environmental research.

The R&A definition of sustainability in relation to golf course development and management is: "Optimising the playing quality of the golf course in harmony with the conservation of its natural environment under economically sound and socially responsible management".

(Royal and Ancient, 2007). Additionally, the USGA has funded more than $15 million dollars of research investigating the environmental fate of chemicals applied to golf courses and more environmentally compatible approaches to golf course management (Clark and Kenna, 2000). However, most recommendations for improving the sustainability of course management are based on highly controlled experimental plot research, or on anecdotal information generated from case studies.

Golf turf management-based research is often conducted looking at two or three aspects of turfgrass culture such as mowing, fertilizing and irrigation (Miltner et al., 2005) or the interaction of a cultural practice such as irrigation on pest occurrence and management (Busey and Johnston, 2006). For example, Ingugiato et al. (2008) found that nitrogen fertilization, plant growth regulators and vertical mowing interacted to effect anthracnose caused by *Colletotrichum cereale* Manns Manns sesnu lato Crouch, Clarke and Hillman. In spite of multiple interactions, nitrogen fertilization had the greatest influence on disease levels. Additionally, Huang et al. (2000) showed the favorable influence of increased mowing heights on plant energy dynamics that results in healthier plants. However, very few managers have implemented increased fertility or increased mowing height programs because of the perceived negative effect on ball roll distance—an important putting green performance indicator.

There are mowing strategies available for reducing the stress of mowing by allowing the turf to rest (Madison, 1962). Howieson and Christians (2008) showed how reducing mowing frequency from seven days per week to five days per week improved plant health. These types of cultural practices that reduce stress on turfgrass plants could be important for reducing pest incidence and severity on a putting surface but have not been assessed in actual golf course situations and therefore have not received widespread acceptance.

In addition to the cultural information, research has been conducted investigating biological control products integrated with cultural management programs. For example, Lee et al. (2003) investigated the effects of a plant defense activator and biostimulants on turfgrass diseases. In that study it was shown that in some cases the incidence of fungal disease increased in response to biostimulant applications. A more comprehensive study conducted by Tomaso-Peterson and Perry (2007) investigated the effect of biofungicides and organic fertilizers on dollar spot caused by *Sclerotinia ho-*

meocarpa F.T. Bennet. This study demonstrated a significant interaction between biofungicides and organic fertilizer that lead to a reduction in disease incidence. However, as with previous studies, these projects are conducted on experimental plots not subject to actual golf traffic and without integration into the broader golf turf management systems.

Long-term management system-based research (often abbreviated LTAR for Long Term Agricultural Research) has become common-place in production agriculture. The LTAR compares conventional management systems to alternative management such as organic or no-till agricultural systems (Posner and Hedtcke, 2008; Smith and Menalled, 2007). It is not uncommon to have 7 to 19 different components to a management system from crop rotation to planting technique and fertilization. Additionally, these projects are conducted over 8 to 15 year periods or longer and strive to develop a deeper understanding of the long-term functioning of management systems and their resiliency. Finally, long-term systems-based research can provide robust solutions to problems in the context of climatic, social, ecological and other factors that change on longer time-scales (Robertson et al., 2006).

Golf turf management is a system that conditions a golf course to meet the needs of the golf playing public. Unlike agriculture that can measure yield, golf turf performance requires quantitative measures developed by turfgrass scientists but also qualitative measures from both established scientific assessment (turfgrass quality) and end-user satisfaction. A comprehensive and long-term investigation of integrated cultural and pest management systems, less reliant on chemical pesticides for golf turf that includes the scientific and subjective measurement has not been conducted.

The objective of this project was to investigate the long-term effect of conventional and alternative cultural and pest management programs designed to reduce reliance on chemical pesticides on the quality and performance of golf putting surfaces.

MATERIALS AND METHODS

Site Description

The seven-year study was initiated in April 2001 at the Bethpage State Park in Farmingdale, NY (40° 44′ 0″ N, 73° 26′ 42″ W). The Bethpage State Park is a 600 ha park with five golf courses. The study was conducted on the 18 putting surfaces of the Green Course that average about 440 m^2 and accommodate approximately 50,000 18-hole rounds of golf over a 9 to 12 month period depending on winter weather conditions. During the period of the study the largest amount of play was 62,000 rounds in 2001 and lowest rounds recorded were 42,000 in 2004.

The Green Course putting surfaces consisted of a mixed stand of annual bluegrass [*Poa annua* L. f. *reptans* (Hauskins) T. Koyama] and creeping bentgrass [*Agrostis stolonifera* L.] originally planted in 1932 on a Bridgehampton fine sandy loam, Typic Dystrochrepts. The surfaces were aggressively amended for three years prior to the initiation of the study with sand topdressing meeting USGA specifications for putting green construction. The final sand-based profile measured 8cm. In addition, putting surfaces were initially evaluated for microclimate factors and historical pest pressure.

Site characterization included soil chemical analysis using the Morgan extraction and organic matter determined by

Table 1a. Initial (2001) soil chemical analysis of Green Course putting surfaces, Farmingdale, New York, USA.

Treatment		**pH**	**Organic Matter (%)**	**S**	**P**	**Ca**	**Mg**	**K**	**Na**
Cultural Management	*Pest Management*					g kg^{-1}			
Conventional	Conventional	6.9	4.1	58	282	1711	257	95	22
Conventional	IPM	7.1	3.2	56	290	1322	277	97	23
Conventional	Bio-Based	6.9	3.6	55	333	1586	254	95	24
Alternative	Conventional	7.0	3.8	56	283	1596	266	92	21
Alternative	IPM	6.9	4.1	55	245	1571	254	98	20
Alternative	Bio-Based	6.8	4.0	58	247	1677	256	89	23
	Tukey's LSD	NS	NS	NS	NS	NS	NS	NS	NS

Table 1b. Final (2008) soil chemical analysis of Green Course putting surfaces, Farmingdale, New York, USA.

Treatment		**pH**	**Organic Matter (%)**	**S**	**P**	**Ca**	**Mg**	**K**	**Na**
Cultural Management	*Pest Management*					g kg^{-1}			
Conventional	Conventional	6.6	4.6	35	229	1209	180	58	40
Conventional	IPM	6.6	3.1	28	225	825	125	49	40
Conventional	Bio-Based	6.5	3.1	32	185	975	165	52	49
Alternative	Conventional	5.4	3.7	26	92	625	52	45	41
Alternative	IPM	5.0	3.6	59	95	242	55	36	46
Alternative	Bio-Based	5.4	3.6	21	99	455	45	40	38
	Tukey LSD	0.5	0.4	14	35	206	27	NS	NS

Table 2. Analysis of variance and contrasts of cultural management programs on soil chemical properties implemented during study to evaluate reduced chemical management programs at Bethpage Green Course, Farmingdale, NY.

Source	**df**	**Estimate**	**Pr > | t |**	**Pr > F**
Time	8			***
TRT	5			***
CC v. AC	17	-0.150	0.0122	
Time x TRT	40			NS

*, **, *** F-value significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

weight loss on ignition (Table 1a,b and Table 2). The study consisted of two cultural management systems and three pest management systems in a completely randomized design in a full factorial arrangement resulting in six treatments with three replicates.

Cultural Management Systems

The two cultural management systems were defined as conventional and alternative. The conventional cultural management system (CC) involved mowing, watering, fertilization, cultivation, topdressing, rolling, vertical mowing, and other practices, and was based on current management strategies employed at three other golf courses at Bethpage State Park that serve similar golfing clientele. The goal of the conventional management program was to offer an well defined and repeatable set of practices that balance acceptable turfgrass quality with ball roll distances between 2.5 and 2.7 m during the season (Table 3). Fertilizer rates were applied in approximately a 3:1:2 ratio (N:P:K) with annual nitrogen rates between 122 kg N ha^{-1} and 250 kg N ha^{-1}.

Table 3. Cultural management systems implemented during the project to reduce chemical pesticide use on putting surfaces at Bethpage Green Course, Farmingdale, NY (2001-2008).

Practice	Conventional	Alternative
Mow Heights	2.5mm to 3.25mm	3.25mm to 4.7mm
Mow Frequency	6 to 7 times per week	3 to 5 times per week
Perimeter Cut	4 to 6 times per week	2 to 3 times per week
Rolling	No more than 2 times per week	3 to 5 times per week
Fertilization	Balanced fertility with a variety of nutritional supplements and biostimulants	Nitrogen only supplied as either ammonium sulfate or urea and iron sulfate. In 2006 began regular application of seaweed extract
Irrigation	Always after 20:00	Following mowing usually before 8:00 after mow or roll
Plant Growth Regulators	Light and frequent trinexapac-ethyl applications and annual bluegrass seedhead suppression with ethephon	Starting in 2005 light and frequent trinexapac-ethyl applications and ethephon for annual bluegrass seedhead suppression
Cultivation	Hollow tine cultivation two times per year with cores removed	6 times per yr. (hollow and solid tine plus water injection cultivation every 3 weeks during season). Hollow coring including core removal
Topdressing	Every three weeks depending on growth	No less than every two weeks depending on growth that often resulted in 25 percent more material applied than conventional system

The alternative cultural management system (AC) was designed to reduce turfgrass stress as the first priority with ease of implementation being secondary (Table 3). It was hypothesized that by reducing the plant stress associated with conventional management systems we would enhance the plants' abilities to withstand pest and environmental pressures thereby reducing the need for chemical pesticide use. Fertilizer was exclusively nitrogen as ammonium sulfate or urea at annual rates between 200 kg N ha^{-1} to 300 kg N ha^{-1} and iron as iron sulfate. No other nutrients were applied in an effort to favor an increase in creeping bentgrass (Kamp, 1981).

Practices in the alternative management system were limited by the goal of attaining a minimum ball roll of 2.3m. Therefore, practices that resulted in unacceptably slow greens were discontinued. In systems-based research identifying the management goal serves as a guide for future repeatability of this research.

In response to catastrophic turf loss in 2001 three putting surfaces were regrassed with sod to velvet bentgrass (*Agrostis canina* L.) "SR7200". Surfacing with this disease-resistant species was considered to be an alternative cultural practice. This left an unbalanced design with six conventional culture and 12 alternative culture surfaces. As a result data were analyzed using linear mixed models with compound symmetric covariance structure to assess over treatment effects when repeated measurements were made on the same experimental unit over time.

Pest Management Systems

The pest management systems were defined as conventional (CPM), integrated pest management (IPM), or biologically-based (BBPM). The conventional pest management system has relied primarily on traditional calendar-based applications of pesticide products that are legal for use in Nassau and Suffolk Counties in NY. The CPM also included additional curative applications during pest epidemics. Interestingly, Nassau and Suffolk counties have slightly more restrictive pesticide selection criteria than the remainder of New York State as a result of previously contaminated groundwater (Attorney General of New York State, 1995). The CPM approach was also conducted on the other four courses in the park, but has been altered since 2005 in response to a park-wide policy to reduce the cumulative toxicity of products used.

The IPM program utilized cultural, biological and chemical approaches to prevent and minimize pest problems. The nature of the IPM approach is inherently dynamic, as actions are based on environmental conditions and pest pressure assessed by monitoring (Schumann et al., 1997). As the study progressed and additional scouting data were collected, some preventive chemical applications were incorporated into the IPM systems to avoid catastrophic turf loss.

The biologically based pest management system (BBPM) emphasized cultural and biological practices exclusively in the first three years of the study. In 2001 there were very few biological control products with acceptable databases of performance. Therefore, due to catastrophic failure of the non-chemically treated putting surfaces in 2001 under this treatment in the first three years during the July to August period we altered the definition of the BBPM. New products included reduced-risk pesticides as defined by the United States Environmental Protection Agency, bio-pesticides and other products with low environmental impact as measured by the Environmental Impact Quotient (EIQ) (Kovach et al.,1992). Over the seven years of the study, the availability of efficacious pest management products has increased (Tomaso-Peterson and Perry, 2007), thereby improving our ability to manage pests in the BBPM systems.

In-season adjustments to cultural and pest management systems were often made due to tournament scheduling, severe environmental or pest pressure, or lack of adequate labor resources. These types of alterations are common in systems-based research (Posner and Hedtcke, 2008). However over the seven years of the study every effort was made to ensure the integrity of the treatments.

Data Collection

Turfgrass quality was rated visually at least once each month from March through October, using a 1 to 9 scale, with 1 = completely necrotic, dead turf; 6 = minimally acceptable putting surface turf; and 9 = optimal density, uniformity and color. Ball roll measurements (six rolls, three in each direction) were recorded from each putting surface with a USGA Stimpmeter at least once per month from April through October in most years. Ball roll was measured after turf had been mowed and/or rolled prior to irrigation. Distances of the six rolls were averaged for data analysis. The labor time required for all cultural and pest management practices was recorded.

This study required a systematic method for assessing the environmental impact of all pest management products or a pesticide risk indicator model. This experiment used the Environmental Impact Quotient (EIQ) (Kovach, 1992). The EIQ utilizes available toxicological, environmental fate, formulation, and application rates in a derived algorithm that quantifies pesticide ecological risk as well as risk to consumers, applicators.

Greitens and Day (2007) determined the EIQ provided the most measurement validity among eight pesticide risk indicator models assessed. Specifically, the EIQ had the most constant, statistically significant correlation with pesticide application rate across different farms, application strategies and years. Finally, Quin and Edwards-Jones (1997) stated the EIQ method possesses features that predispose it for use in policy and environmental decision-making.

A golfer satisfaction survey was administered on the Green Course annually in the August/September period from 2003-2007 on random playing days and times. A total of 693 surveys were collected Immediately after playing each hole, they rated the putting green for overall quality, and acceptability of the ball roll. In addition, they answered questions regarding their attitudes toward pesticide use on public golf courses, their perceptions of the Green Course, and provided general demographic information.

Data analysis was conducted using linear mixed models fitted by the restricted maximum likelihood (REML) method (JMP Version 7.0, SAS Inst., Inc., Cary, NC, USA). Orthogonal contrasts were established and means were separated using Tukey's separation at alpha=0.05.

RESULTS AND DISCUSSION

Soil Chemical Analysis

Soil chemical properties, assessed using the Morgan extraction on a composite soil sample collected from an 8cm depth were dramatically influenced by cultural and pest management programs over the seven years of the study (Table 1b and Table 2). Organic matter was determined by weight loss on ignition. The AC program reduced pH levels an average of 1.3units most likely from continued use of acidifying fertilizers and no supplemental lime applications. This dramatic decline was obvious for all AC greens independent of pest management program.

All nutrient levels were significantly reduced over time, independent of management system. However, in every case the AC soils were reduced at least two fold more than the CC programs. Soil potassium levels (K) declined but were not affected by treatments.

In general organic matter levels remained the same or declined in all treatments except the CPM treatments likely related to the reduced amount of topdressing applied to these treatments compared to alternative culture. Organic matter levels substantially increased in CPM under CC and declined only slightly in CPM when under

Table 4. Annual turfgrass quality ratings for putting surface treatments for years when interactive effects were significant during study to evaluate reduced chemical management programs at Bethpage Green Course, Farmingdale, NY.

Treatment	2002	2003	2005	2006	2007
Conventional Culture / Conventional Pest Management	7	7	7	6.9	7.1
Alternative Culture / Conventional Pest Management	7.6	6.9	7.2	6.7	7
Conventional Culture / Integrated Pest Management	6.6	6.3	6.8	6.3	6
Alternative Culture / Integrated Pest Management	7.3	6.2	7	6.3	5.4
Conventional Culture / Bio-based Pest Management	5.6	5.2	6.9	6.1	5.8
Alternative Culture / Bio-based Pest Management	5.9	5.7	6	5.9	5.4
Tukey's LSD	0.4	0.6	0.3	0.4	0.5

AC. There is some evidence that pesticide use can lead to decreased organic matter degradation (Smiley et al., 1985) and any possible increases might have been mitigated by more aggressive cultivation and topdressing conducted in the AC treatments.

Turfgrass Quality

Annual turfgrass quality ratings were significantly influenced by treatments. The CPM treatment was the least influenced over time and provided consistent high quality turf independent of cultural management system (Table 4).

Orthogonal contrasts indicate there was only a slight difference in turfgrass quality between cultural management systems when using CPM or IPM (Tables 5a-c). However there was a significant reduction in turfgrass quality with IPM and BBPM within the CC system. In general the reduction in turfgrass quality associated with the IPM system specifically within the CC system was minimal (Table 4). The ability of the IPM treatment to maintain acceptable turfgrass quality, albeit not as high as CPM, supports the concept that an IPM program can provide consistently acceptable playing conditions.

The BBPM treatment failed to provide acceptable turfgrass quality in three of the six seasons (Table 4). However the IPM systems provided acceptable quality turf in all but one season and that was only under the AC system.

Within every growing season there was a significant reduction in turfgrass quality in the July to August months (data not shown). The summer period was often when there was an observed increase in fungal disease pressure primarily conditions favorable for brown patch (*Rhizoctonia solani*), Pythium blight (*Pythium spp.*), summer patch (*Magnaporthe poae* Landschoot and Jackson), and dollar spot. Results indicate preventive pesticide use, as in CPM, may sometimes be necessary to avoid significant reduction of turfgrass quality in the stressful summer months.

Tables 5a-c. Analyses of variance and contrasts of treatment effects on turfgrass quality during the study to evaluate reduced chemical management programs at Bethpage Green Course, Farmingdale, NY.

Table 5a. Year 3 (2003).

Source	df	Estimate	Pr > | t |	Pr > F
Time	7			***
Treatment	5			***
CC/CPM v. AC/CPM	1	NS	0.0613	
CC/IPM v. AC/IPM	1	NS	0.7748	
CC/CPM v. CC/IPM	1	-0.704	0.0131	
CC/CPM v. CC/BBPM	1	-1.754	<0.0001	
AC/CPM v. AC/IPM	1	-0.646	0.0205	
Time x Treatment	30			***

Table 5b. Year 6 (2006).

Source	df	Estimate	Pr > | t |	Pr > F
Time	8			***
Treatment	5			***
CC/CPM v. AC/CPM	1	-0.176	0.0244	
CC/IPM v. AC/IPM	1	NS	0.9236	
CC/CPM v. CC/IPM	1	-0.563	<0.0001	
CC/CPM v. CC/BBPM	1	-0.733	<0.0001	
AC/CPM v. AC/IPM	1	-0.394	<0.0001	
Time x Treatment	40			*

Table 5c. Year 7 (2007).

Source	df	Estimate	Pr > | t |	Pr > F
Time	8			***
Treatment	5			***
CC/CPM v. AC/CPM	1	NS	0.6649	
CC/IPM v. AC/IPM	1	NS	0.1136	
CC/CPM v. CC/IPM	1	-1.096	0.0063	
CC/CPM v. CC/BBPM	1	-1.3	0.0021	
AC/CPM v. AC/IPM	1	1.516	0.0006	
Time x Treatment	40			***

*, **, *** F-value significant at the 0.05, 0.01, and 0.001 probability levels, respectively.

The re-grassing of putting surfaces for the AC-BBPM treatment to velvet bentgrass did not produce the desired results of increased turf quality under reduced chemical management. In fact turfgrass quality was consistently the lowest of any treatment. This could be due to intense heat and high levels of traffic. Still, this is not consistent with existing reports of Samaranayake et al. (2008) who reported acceptable traffic and pest tolerance under simulated traffic conditions on controlled field plots in NJ.

It could be speculated that the failure of the velvet bentgrass to provide acceptable quality turf could be related to the use of sod as there is anecdotal evidence that seeding is the preferred method of establishment. While this is possible, it is worth noting that the sod was produced on a sand-based medium similar to putting surface medium. Furthermore, during the first year of establishment in 2002, no less than five hollow tine cultivation events combined with sand incorporation were conducted in an effort to more effectively manage the known organic matter issues associated with velvet bentgrass.

There is little question regarding the benefits of pesticides for providing consistent conditions in long-term studies (Posner and Hedtcke, 2008; Smith and Menalled, 2007). Additionally, while studies have demonstrated the benefit of biological or reduced risk disease control methods (Tomaso-Peterson and Perry 2007) these studies were conducted on experimental plots under little to no traffic and ideal maintenance conditions. Further integration of products and practices is required to more thoroughly understand performance on an operating golf course.

Ball Roll

There was no significant effect of cultural or pest management treatment on ball roll distances over the seven years of the study (data not shown). In general ball roll distance targets were achieved on a regular basis.

Ball roll distance maintained a seasonal trend with the greatest distances often achieved in spring and fall and lowest distances in summer. Interestingly while turfgrass quality was significantly reduced under all pest management programs when compared to CPM, there were little to no differences in ball roll distance. This point demonstrates the ability to maintain functional quality in spite of reduced visual quality.

Environmental Impact of Pest Management Practices

The EIQ model has been assessed recently to determine risk when comparing alternative management models (Stenrod et al., 2008). This study concluded that while there are limitations relative to the ability of the EIQ to assess the risk of persistent products, it provides an excellent general assessment of environmental risk based on amount of material. Smith et al., (2002) found a significant correlation between pesticide application rate and the use of the EIQ and concluded that the EIQ allowed researchers and practitioners to integrate agricultural needs with environmental factors when comparing growing systems.

There were significant differences among the treatments for the environmental impact from 2004 to 2007 (Figure 1). Reductions ranged from 49% for AC/IPM to 96% for AC/BBPM when compared to CPM independent of cultural treatment.

A primary goal of instituting an IPM or BBPM system is to reduce environmental impact as measured by the EIQ. The data demonstrate a three-fold decrease in overall risk in the CPM programs from 2005 to 2007, independent of cultural management. This was spurred by the park-wide policy enacted in 2006 to reduce risk by decreasing the environmental impact as measured by EIQ of conventional pest management programs on all Bethpage courses. This response while not quantifiable suggests that the use of an EIQ model has provided the superintendent with a tool to differentiate among pesticides and has begun to influence pest management decision-making at the park.

Labor Allocation

Labor hours allocated to each treatment were monitored and recorded during the seven years of the study. Hours were tracked according to total labor, labor for culture and labor for pest management. The variable nature of the season and the familiarity with various practices and products was revealed in the data when viewed over time (Table 6).

As the study progressed and certain cultural and pest management practices were altered, i.e., decreased scouting needs, increased pesticide applications based on pest pressure and variable pest pressure, the IPM program began to emerge as the least labor intensive--especially when compared directly between AC and CC. The AC/IPM treatment had significantly less labor allocated to pest management than CPM.

Very little data exists regarding the labor required to implement broad-based changes in management. Williams et al. (2005) assessed the implementation of IPM in schools. Integrated pest management services were significantly more time-consuming, and therefore had higher labor costs than conventional services. Nevertheless, in that study the two types of treatments incurred similar total costs, and the efficacy of both treatments was also similar. Most importantly, pest monitoring, a central element of the IPM program, revealed fewer insects and indicated that most of the conventional pesticide treatments were unnecessary.

There are important questions remaining regarding the value of the AC system as it does appear to increase labor and does not result in reduced time allocated to pest management. In fact throughout the study the AC/CPM required significantly more total labor as well as pest management labor.

Table 6. Putting surface treatment effects on labor allocation in total hours per season.*

	2002		2004		2007	
Treatment	**Total**	**Pest Mgt.**	**Total**	**Pest Mgt.**	**Total**	**Pest Mgt.**
AC/CPM	3036 a	233 a	3307 a	597 a	3066 a	410 a
AC/IPM	2769 ab	197 ab	2605 b	69 c	2350 d	268 b
AC/BBPM	2708 abc	197 ab	2639 b	125 bc	2748 ab	352 ab
CC/IPM	2195 bcd	150 b	2810 ab	136 b	2530 abc	352 ab
CC/BBM	1974 cd	55 c	2976 ab	159 b	2411 bcd	284 ab
CC/CPM	1765 d	45 c	2886 ab	155 b	2370 cd	284 ab

*means within columns followed by different letters are significantly different at $p<0.05$ based on Tukey's Mean Separation.

Table 7. Five year summary of putting surface treatment effect on golfer satisfaction with ball roll and visual quality.*

Treatment	Turf Quality[t]	Ball Roll
CC/CPM	3.7 a	3.1 a
AC/CPM	3.6 a	3.1 a
CC/IPM	3.6 a	3 ab
AC/IPM	3.5 a	3 ab
CC/BBPM	3.5 a	3 ab
AC/BBPM	2.9 b	2.9 b

* Turf quality response options: 1=very poor, 2=fair, 3=acceptable, 4=very good, 5=excellent; Ball roll response options: 1=too slow, 2=slow but OK, 3=acceptable speed, 4= fast but OK, 5=too fast.

[t]means within columns followed by different letters are significantly different at p<0.05 based on Tukeys Mean Separation.

Golfer Satisfaction Survey

There were few significant differences among the treatments for golfer satisfaction with turfgrass quality or ball roll distances (Table 7). Only the AC/BBPM treatment fell below acceptable quality and adequate speed during 2003 to 2007.

Interestingly very few unacceptable quality ratings were recorded during the study suggesting that there might be some flexibility in altering visual quality. Based on the study data, the Bethpage Green Course is meeting golfer expectations even when there are significant differences and often reductions in turfgrass quality and ball roll distances. It appears that some alteration of turfgrass quality and performance may be more acceptable than may have been previously thought for the golfing public.

As pressure to reduce pesticide use continues, recognizing from the impact of various conventional and alternative management systems on golfer satisfaction is vital. Our data suggest that golfers will tolerate some variability in quality, though we know anecdotally that they are not accepting of total turf loss and playing on temporary greens.

CONCLUSION

Reduced chemical management of putting surfaces presents a unique challenge to the golf turf industry. There are valid concerns regarding the availability of effective cultural and biological alternatives to conventional programs. The CPM program helped to maintain the highest level of turfgrass quality over the seven years of the study, but IPM programs also maintained acceptable turfgrass quality over the same period. The BBPM did not result in consistently acceptable visual turf quality. Functional quality as measured by ball roll was virtually consistent across all treatments demonstrating that surfaces with reduced visual quality can still maintain functional performance. There was a clear trend for increased labor associated with alternative cultural management independent of pest management system. When assessing overall environmental impact using the pesticide risk indicator model (EIQ), the IPM and BBPM reduced risk as much as 95% in some years compared to CPM. Long-term management system research offers the opportunity for a broad perspective on slowly changing factors such as labor allocation trends and end-user satisfaction. In this study golfers seemed indifferent to the wide range of visual quality and ball roll measurements--as their responses indicated that both were acceptable. Much more work is needed to fully integrate emerging practices and products capable of reducing reliance on chemical pesticides. However, existing IPM programs do offer the potential to reduce the risk associated with pesticide use and maintain performance with little increase in labor expenditures over time.

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REFERENCES

Busey, P. and D.L. Johnston. 2006. Impact of cultural factors on weed populations in St. Augustine turf. Weed Sci. 54:961-967.

Clark, J.M. and M.P. Kenna (eds). 2000. Fate and management of turfgrass chemicals. ACS Symposium Ser. 522, Am. Chem. Soc., Washington, D.C.

This one's not cited, did you mean to at very beginning? European Commission, Communication from the Commission on the Precautionary Principle, Brusells (2000).

Fisher, Elizabeth, Judith Jones & Rene von Schomberg (eds). 2006. Implementing the Precautionary Principle: Perspectives and Prospects, Cheltenham, UK and Northampton, MA.

Greitens, T.J. and E. Day. 2007 An alternative way to evaluate the environmental effects of integrated pest management: Pesticide risk indicators. Renew. Ag. & Food Systems 22(3):213-222.

Howieson, M. J., and N. E. Christians. 2008. Carbohydrate metabolism and efficiency of photosystem II in mown creeping bentgrass (Agrostis stolonifera L.). HortScience. 43(2):p. 525-528.

Huang, B., X. Liu, J. Fry, and M. Kenna. 2000. Burning the candle at both ends: High temperatures and low cutting heights lead to a dead end! USGA Green Section Record. 38 (3):15-16.

Inguagiato, J.C., J.A. Murphy, and B.B. Clarke. 2008. Anthracnose severity on annual bluegrass influenced by nitrogen fertilization, growth regulators and verticutting. Crop Sci. 48:1595-1607.

Kamp, H. A. 1981. Annual Meadow-grass (Poa annua) - a Dutch viewpoint. J. Sports Turf Res. Inst. 57:p. 41-48.

Kleter,G.A, R. Bhula, K. Bodnaruk, E. Carazo, and S.S. Wong. 2007. Altered pesticide use on transgenic crops and the associated general impact from an environmental perspective. Pest-management-science, 63(11): 1107-1115.

Kovach, J., C. Petzoldt, J. Degni, and J. Tette. 1992. A Method to Measure the Environmental Impact of Pesticides. New York Agricultural Experiment Station Bulletin #139. Cornell University, Ithaca, NY, 8pp.

Lee, J., J. Fry and N. Tisserat. 2003. Dollar spot and brown patch incidence in creeping bentgrass as affected by acibenzolar-s-methyl and biostimulants. HortScience 38(6):1223-1226.

Levitan, L., I. Merwin and J. Kovach. 1995. Assessing the Relative Environmental Impacts of Agricultural Pesticides: The Quest for a Holistic Method. *Agriculture, Ecosystems and Enviroment*. 55: 153-168.

Madison, J. H. 1962. Mowing of turfgrass. III. The effect of rest on seaside bentgrass turf mowed daily. Agron. J. 54(3):p. 252-253.

Miltner, E.D., G.W. Stahnke, and G.J. Reinhart. 2005. Mowing height, nitrogen rate, and organic and synthetic fertilizer effects on perennial ryegrass quality and pest occurrence. Intl. Turf Soc. Res. J. 10:982-988.

Office of New York State Attorney General. 1995. Toxic Fairways: Risking Groundwater Contamination From Pesticides on Long Island Golf Courses. 17 pp. [NY].

Posner, J.L. and J.L. Hedtcke.2008. Organic and conventional production systems in the Wisconsin integrated cropping systems trial: I Producivity 1990-2002. Agron. J., 100:253-260.

Racke, K.D. 2000. Pesticides for turfgrass pest management; uses and environmental issues, p. 45-64. *In*: J.M. Clark and M.P. Kenna (eds) Fate and management of turfgrass chemicals. ACS Symposium Ser. 522, Am. Chem. Soc., Washington, D.C.

Royal and Ancient. 2007. https://www.bestcourseforgolf.org/content/management/the_sustainable Checked July 12, 2008.

Samaranayake, H., T. J. Lawson, and J. A. Murphy. 2008. Traffic stress effects on bentgrass putting green and fairway turf. Crop Sci. 48(3):p. 1193-1202.

Schumann, G.L., P.J. Vittum, M.L. Elliott, and P.P. Cobb. 1997. IPM Handbook for Golf Courses. vii, 264 pp., + plates. Chelsea, MI: Ann Arbor Press.

Smiley, R. W., C. M. Fowler, R. T. Kane, A. M. Petrovic, and R. H. White. 1985. Fungicide effects on thatch depth, thatch decomposition rate, and growth of Kentucky bluegrass. Agron. J. 77(4):p. 597-602.

Smith, D.T. M.K. Harris, and T.X Liu. 2002. Adoption of pest management practices by vegetable growers: A case study. American Entomologist 48(4): 236-242.

Smith, R.G. and F.D. Menalled. 2007. Temporal yield variability under conventional and alternative management systems. Agron. J. 99:1629-1634.

Stenrod, M., H.E. Heggen, R.I. Bolli, and O.M. Eklo. 2008. Testing and comparison of three pesticide risk indicator models under Norwegian conditions--A case study in the Skuterud and Heiabekken catchments. Agriculture-ecosystems-and-environment. Jan; 123: 15-29.

Tomaso-Peterson, M. and D. H. Perry. 2007. The role of biofungicides and organic fertilizer in the management of dollar spot in Bermudagrass. Online. Applied Turfgrass Science doi:10.1094/ATS-2007-0911-01-RS.

Walmsley, W. H., and A. V. Stewart. 2005. The relative dominance of Agrostis capillaris and Poa annua in relation to soil analysis of golf greens in New Zealand. Int. Turfgrass Soc. Res. J. 10(Part 1):p. 472-478.

Williams, G.M., H.M. Linker, M.G. Waldvogel, R.B. Leidy, and C. Schal. 2005. Comparison of conventional and integrated pest management programs in public schools. J. Econ. Ent. 98(4): 1275-1283.

Woolhouse, A.R. 1976. Estimation of ground cover in turfgrass communities. J. Sports Turf Res. Inst. 52:64–76.