From: Karla Peters <Karla.Peters@co.maui.hi.us>
Sent: Thursday, October 08, 2020 11:21 AM
To: HFC Committee
Cc: Chris Kinzle; Karissa Kaeo; Lisa Sakumoto; Todd Allen
Subject: HFC-14
Attachments: Waiehu Golf turf management program 10-8-20ta_reduced.pdf; Crop Sci.pdf; ITRJ.pdf; benefits of turf AEL 1 revised3.pdf

Aloha Chair Hokama,

Attached is the Department's presentation and supporting documentation for the subject agenda item.

Please let me know if you have any questions.

Thank you!
Karla

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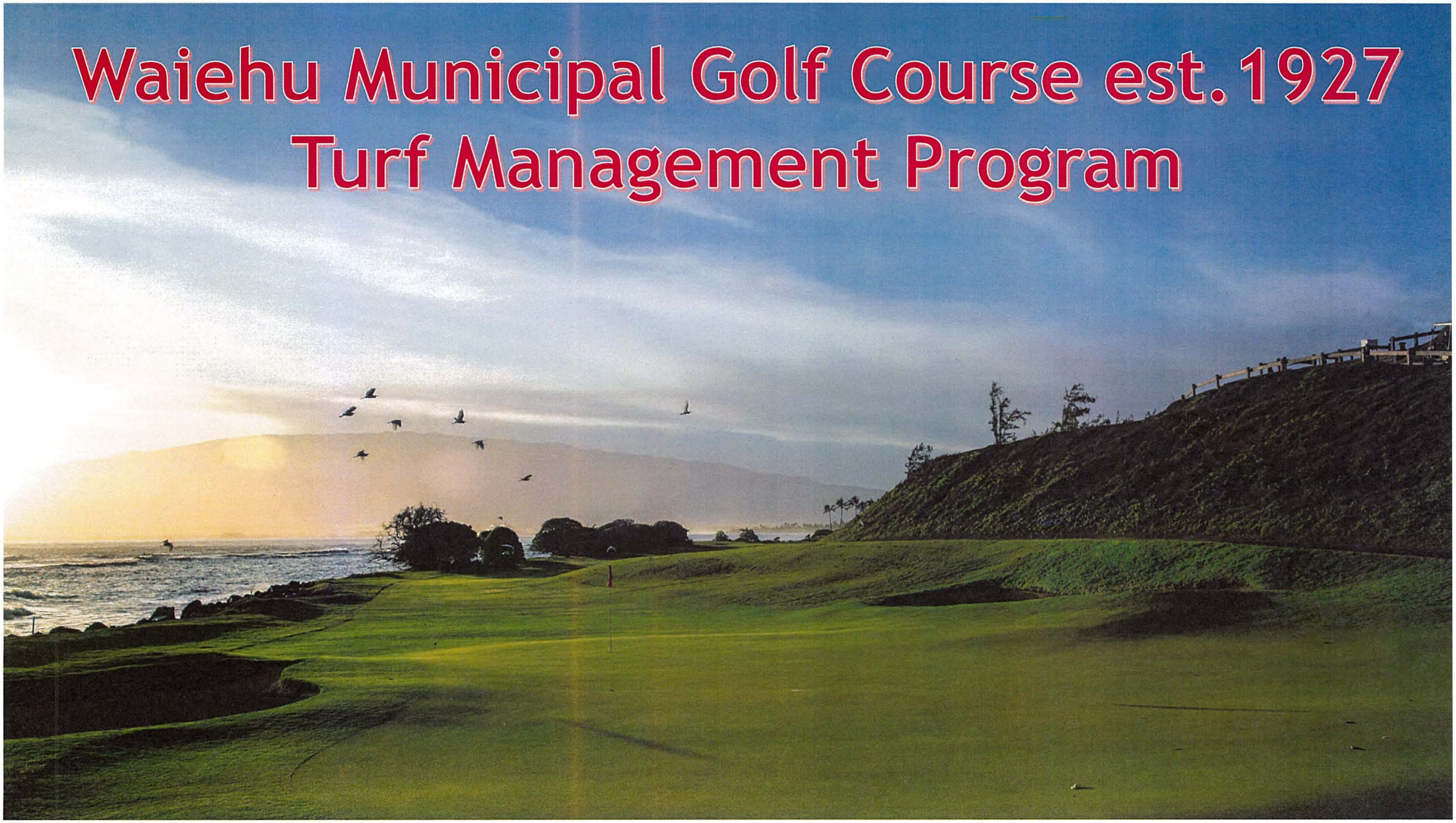
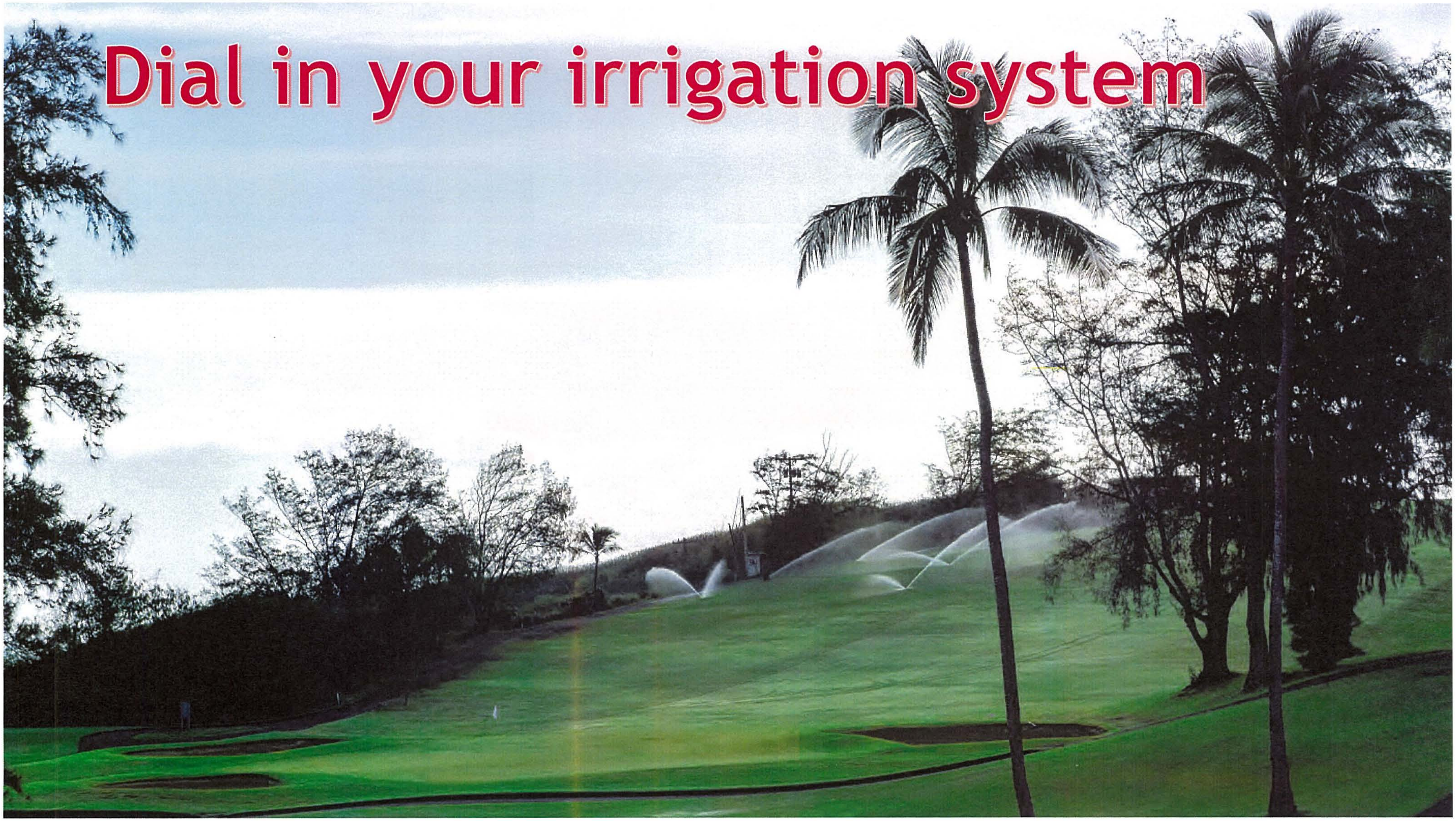
Our Mission: "Provide safe, satisfying and cost effective recreational opportunities for the residents of and visitors to Maui County."

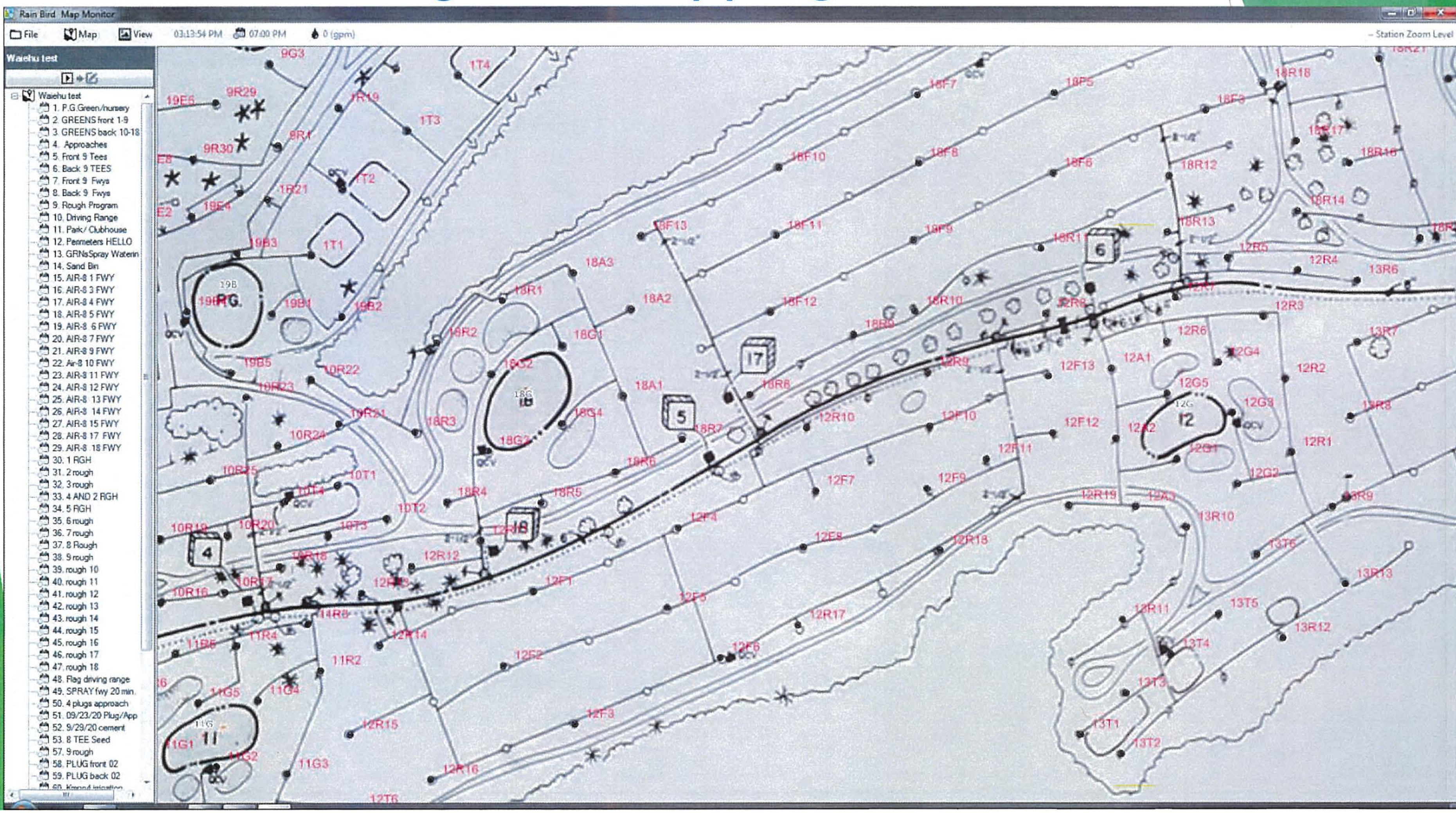

Waiehu Municipal Golf Course est. 1927
Turf Management Program

Irrigation Management by Improving Efficiency

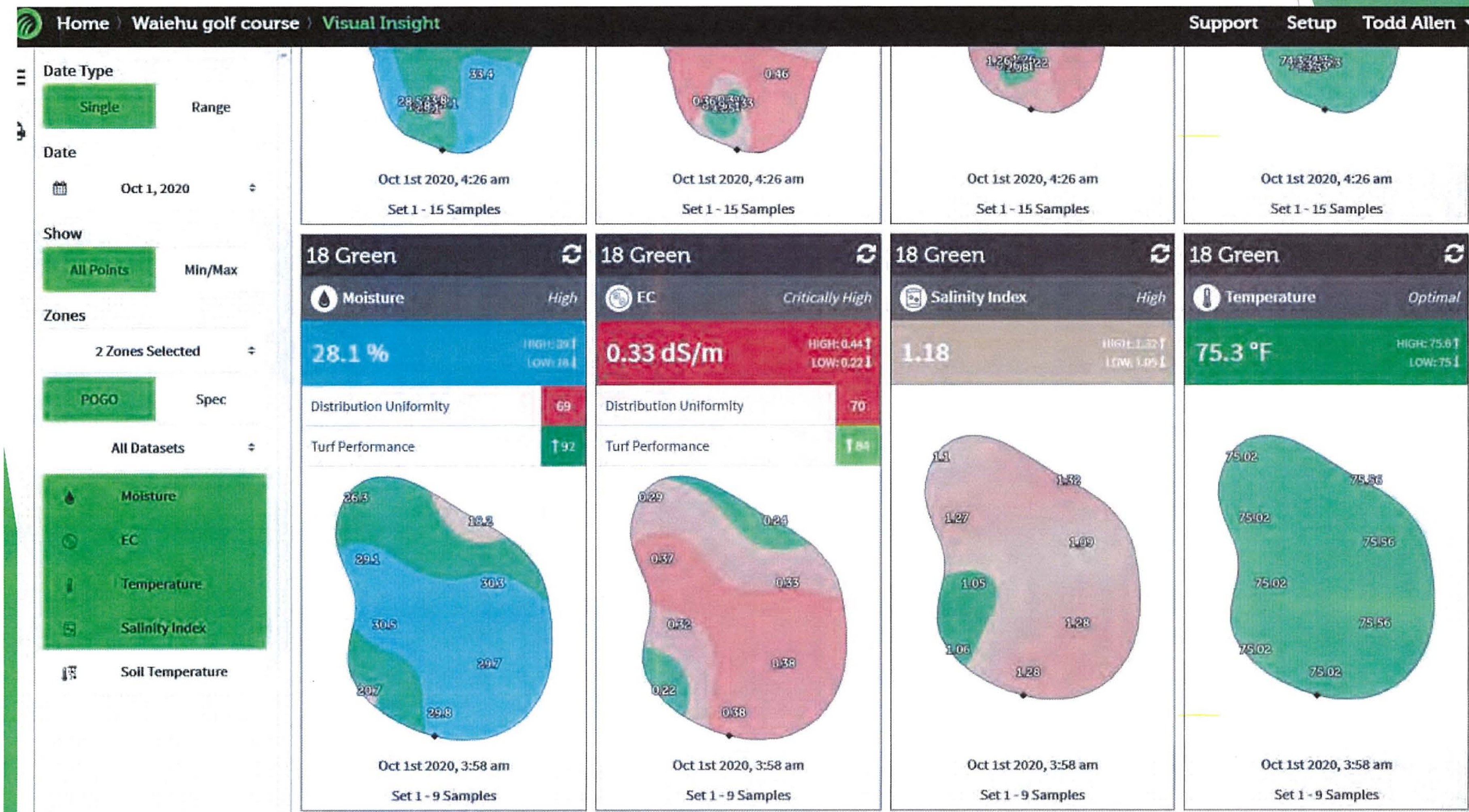
- Continual Assessment of the current Irrigation System, pump station, computer, controllers and sprinklers
- Identify each sprinkler head, pressure and nozzle
- Installed Weather Station to optimize ET rates for our turf
- Reprogrammed RainBird Central Computer System
- Changed watering programs to incorporate Deep and Infrequent watering
- Installed and programmed remote control operations from phone
- Update all Station Data, Sprinkler type, Precipitation Rates, Nozzle and Locations in the computer > 1,400 sprinklers
- Created sprinkler head mapping within the Rainbird software
- Utilize the POGO for irrigation analysis and insight for healthy turf grass

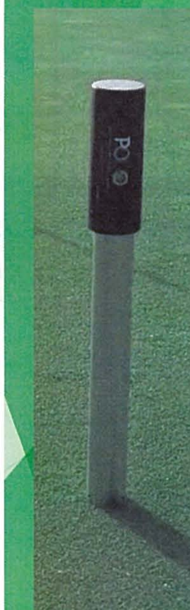

Dial in your irrigation system

Irrigation Mapping at Waiehu



Water Management on the Course Using the POGO

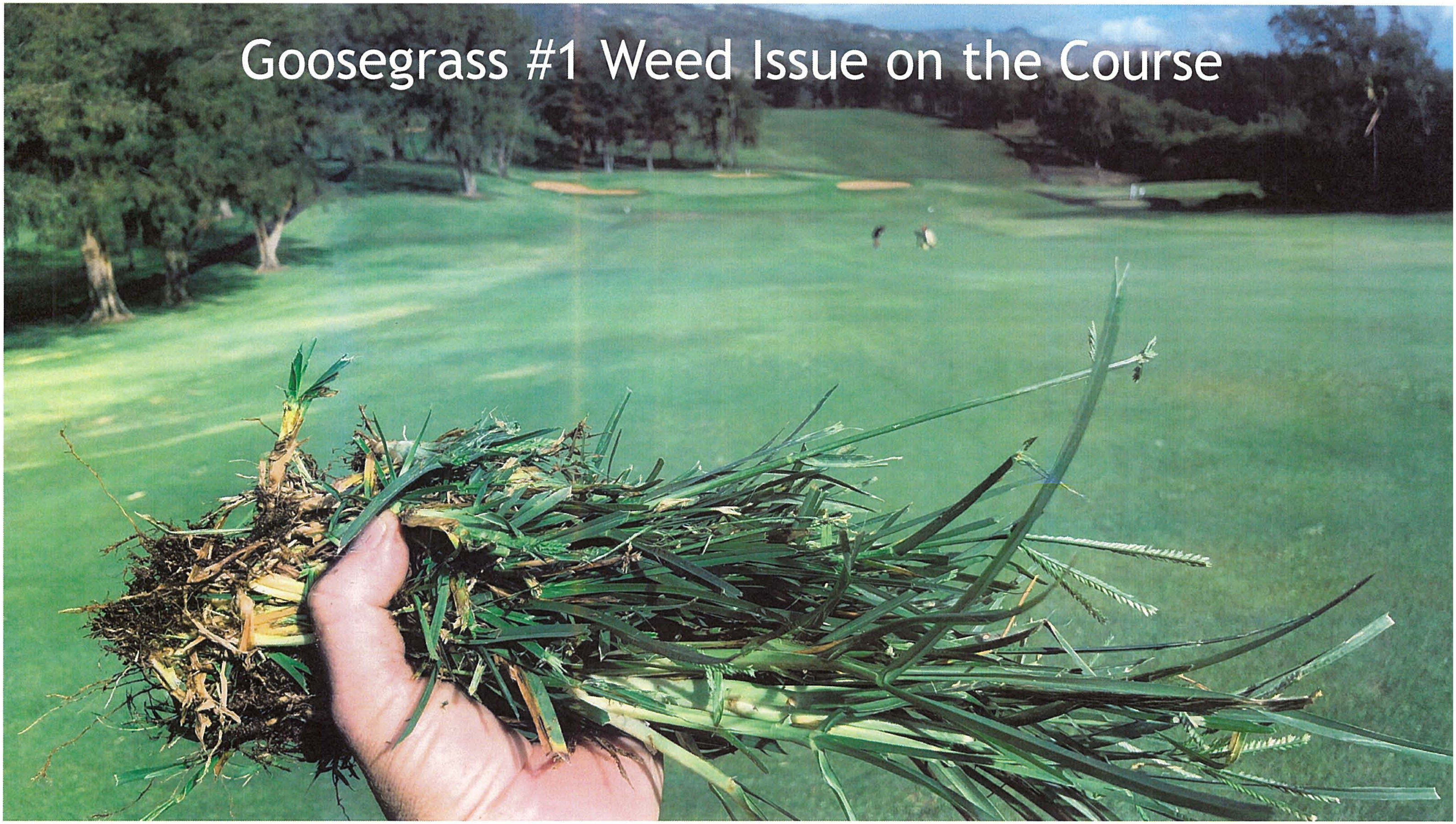




Safe Agronomic Practices for Healthy Turfgrass

- Hawaii Golf BMP- Best Management Practices are science based
- Utilizing Minimum Levels of Sustainable Nutrition
- Using both Granular and Foliar products, Organic Acids, Amino Acids, Glycomic sugars, Antioxidants, Vitamins-Horomones, Micronized Silicon and Vesicular Arbuscular Mycorrhiza (VAM)
- Frequent Verticutting and Light Topdressing to control thatch
- Mowing and rolling greens surfaces
- Aerations are done 2 to 5 times a year and using the AIR2G2, Traditional Aerations, Shockwave and Rotoknife


TAKE ACTION
AGAINST TURF
STRESS
syngenta
Worlds Record for Goosegrass??


Goosegrass #1 Weed Issue on the Course

Safe and effective Pesticide Usage

Waiehu Golf Course Pesticide and Fertilizer usage

Total Acreage : 175 Acres Maintained Turfgrass combination of Seashore Paspalum and Bermuda grass

Greens and Collars: 3.5 Acres paspalum	Tees: 3 Acres Paspalum	Approaches: 1 Acre Paspalum
Fairways: 30 Acres	Driving Range: 3 Acres	Rough on golf Course: 134.5 Acres

Greens and Collar Treatments every 14 to 21 Days depending on Weather Conditions added to 170 gallons H2O

Typical Bi-monthly 1st Treatment

2.5 Gallons Knife Plus 12-0-0+ 6FE, Healthy plant Development Iron, Urea, Manganese, Copper, Sodium Molybdate
2.5 Gallons Astron, root driver and Stress Tolerance, Calcium, Magnesium, Iron, Copper, Zinc
5 gallons Aquatrols Zipline Soil Surfactant, reduces irrigation, strengthens against stress and disease
16.9 oz. Nualgi, Nano Silica, 12 essential nutrients, boosts photosynthesis increases carbon dioxide absorption

Typical Bi-Monthly 2nd Treatment

2.5 gallons Protesyn// organic complex amino acids, proteins, simple sugars, carbohydrates, vitamins
2.5 gallons Renaissance //micronutrient, kelp, antioxidants, bio stimulants
16.9 oz. Nualgi, Nano Silica, 12 essential nutrients, boosts photosynthesis increases carbon dioxide absorption
Preventative Application of Rotational Fungicide if needed (per FRAC codes)

Granular to Tees and Greens

MLSN... Minimum Levels for Sustainable Nutrition //**Granular fertilizer** application done quarterly if needed
Black Gypsum- 70% Gypsum and 30% Humate, improving soil structure, CEC and beneficial soil biology.
Applied at 6- 10 lbs. per 1000 sq. ft. Or 18- 50 lb. bags on 3.5 Acres **Cost $3,671.20 annually**

Contec DG 17-0-17 fertilizer, 17 % Nitrogen from Ammoniacal and Urea Nitrogen , 17% Soluble Potash , 11.8% Sulfur .50 % Iron, .25% Manganese
Applied at 2.94 Lbs. per 1000 sq. ft. Or 11- 40 lbs. Bags on 3.5 Acres **Costs $2,587.50 annually**

Sustane 4-4-4- Bolster, 4% Nitrogen, 4% Phosphate, 4% Potash with 4% Iron and Calcium, .5% Magnesium
Sulfur 1 % ,3% Humic Acid ,1 % Seaweed Extract//includes beneficial V.A. mycorrhizae Fungi, Plant Bio stimulants
Applied at Aerification 25 lbs. per 1000 sq. ft OR 76- 50 lb. bags / **almost 2 Tons** **Costs $ 7,399.96 annually**

Herbicide Applications

Treatment on 33 Acres of Fairways and Driving Range over the summer, 30 to 45 gallons H2O per acre

1.5 oz per Acre of Pylex, topramezone	Caution	no more than 4 oz acre per year
4 oz per Acre Sencor 75 , Metribuzin	Caution	no more than 2 lbs per acre growing season
2 oz per Acre Specticle FLO, Indaziflam	warning	split apps no more than 6 oz per acre annually
11 oz per Acre Brandt M.S.O.	warning	.5 to 2 pints acre
11 oz per Acre Primo Maxx, trinexapac-ethyl	Caution	no more than 305 fl oz per acre annually

300 Gallons of Fertilizer/ water has .08 lb of N and Fe

Spot Spraying to eliminate boom spraying large areas

Depending on weed type targeted which pesticide is in use
15 gallon tank almost all water with 10 oz of Fertilizer
.25 oz Pylex and 1 oz Sencor 75
2 oz Tribute Total
5 oz SpeedZone Red

Vetiver Grass as a Natural Filter

Healthy Soils with Current BMP Program

VAM- Vesicular Arbuscular Mycorrhiza fungi and Beneficial Bacteria

- Glomus intraradices
- Glomus etunicatum
- Glomus deserticola
- Glomus clarum
- Glomus mosseae
- Glomus aggregatum
- Bacillus firmus
- Bacillus amyloliquefaciens
- Bacillus subtilis
- Bacillus licheniformis
- Bacillus megaterium
- Bacillus pumilus
- Bacillus pasteurii
- Bacillus coagulans
- Paenibacillus polymyxa
- Paenibacillus durum

	Report Prepared For: Waiehu Golf Course	Sample Received: 5.2.20 Report Date: 5.6.20	Sample ID All Greens	Sample ID	Sample ID
	ORGANISM	Ideal Range: Turf Grass	Type of Sample: Soil	Type of Sample:	Type of Sample:
NUTRIENT STORAGE	Total Bacteria	300 - 3000 µg/g	1,092		
	Actinobacteria	< 6 µg/g	1		
	Total Fungi	300 - 3000 µg/g	1,758		
	Avg Hyphal Diameter	µm	3.6		
	Total F:B Ratio	1.0	1.6		
NUTRIENT CYCLER	Flagellates	50,000/g combined or >	89,672		
	Amoebae		24,456		
	Bacterial Feeding Nematodes	> 100/g	0		
	Fungal Feeding Nematodes	> 100/g	0		
	Predatory Nematodes	> 100/g	0		
ANAEROBIC INDICATOR	Root Feeding Nematodes	< 100/g	0		
	Ciliates	< 21,000/g	40,760		
	Oomycetes	5% or < Total Fungi µg/g	319		
	COMMENTS:				

EXCELLENT: Ideal functional range

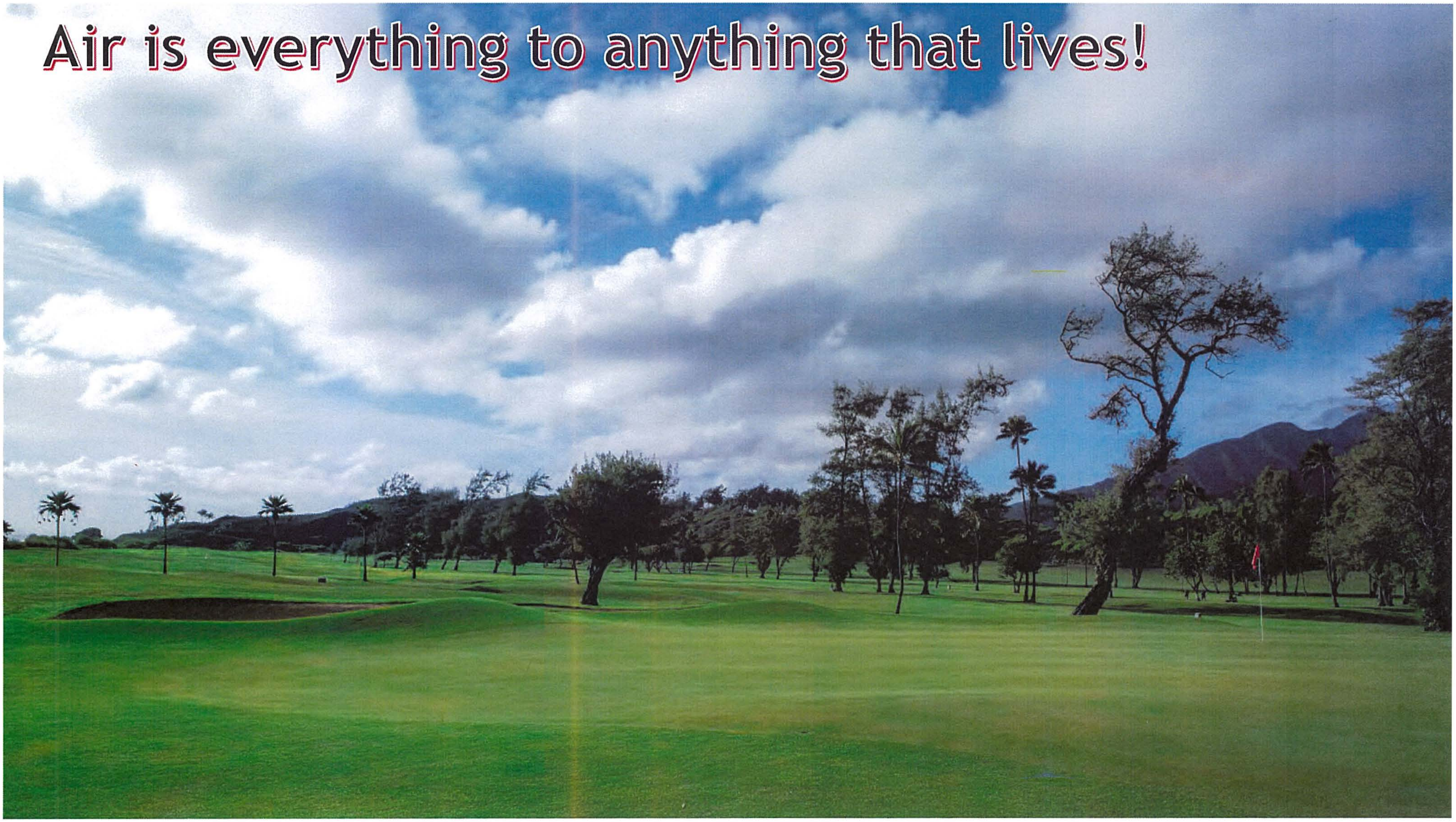
GOOD: Minimum functional range

CAUTION: Outside minimum functional range

DANGER: Undesirable range

CRESCIVE SOIL SERVICES

111 Bank St. #193 Grass Valley, CA 95945 530-256-7878


Air is everything to anything that lives!

Large Crabgrass, White Clover, and Hybrid Bermudagrass Athletic Field Playing Quality in Response to Simulated Traffic

J.T. Brosnan,* K.H. Dickson, J.C. Sorochan, A.W. Thoms, and J.C. Stier

ABSTRACT

Athletic field playing quality encompasses both aesthetics as well as athlete-to-surface interactions that can affect injury incidence. Legislation restricting the use of herbicides on athletic fields may lead to increases in problematic weeds, such as large crabgrass (*Digitaria sanguinalis* L.) and white clover (*Trifolium repens* L.), which could reduce athletic field playing quality and potentially increase potential for athletic injuries. Research was conducted at the University of Tennessee Center for Athletic Field Safety (Knoxville, TN) during 2012 to 2013 to evaluate the playing quality of large crabgrass and white clover compared with weed-free hybrid bermudagrass (*C. dactylon* · *C. transvaalensis* Burtt-Davy, 'Tifway'). All plots (3 by 3 m) were maintained as monostands and subjected to 18 simulated traffic events with a Cady traffic simulator each autumn over 2 yr. Large crabgrass and white clover lost green cover approximately 12 times faster than hybrid bermudagrass in this study. Consequently, surface hardness values on large crabgrass and white clover plots were ~48 to 52% higher than those measured on hybrid bermudagrass after 18 simulated traffic events were applied. Changes in both surface hardness and rotational resistance were significantly correlated ($P < 0.0001$) to changes in green cover following simulated traffic. Our findings indicate that groundcover domination by weeds, such as large crabgrass and white clover, compromises the aesthetics and safety of natural grass athletic fields. Additional research is needed to evaluate athletic field playing quality on polystands of hybrid bermudagrass, large crabgrass, and white clover to determine acceptable thresholds of weed cover for player safety. Information of this nature would be useful for justifying various weed control measures such as herbicide applications.

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Hybrid bermudagrasses [*C. dactylon* (L.) Pers. · *C. transvaalensis* Burtt Davy] are commonly used as athletic field playing surfaces throughout the transitional and warm climatic zones. Many hybrid bermudagrasses offer finer leaf texture and darker green color than common bermudagrass [*Cynodon dactylon* (L.) Pers.] and are tolerant of foot traffic common on athletic fields (Haselbauer et al., 2012; Thoms et al., 2011).

Athletic field playing quality encompasses aesthetics as well as ball- and athlete-to-surface interactions that affect injury incidence (Canaway and Baker, 1993). Foot traffic can have deleterious effects on the quality of hybrid bermudagrass athletic fields. Carrow and Petrovic (1992) explained that foot traffic imposes both wear stress to turfgrass foliage in addition to increasing soil compaction. The cumulative effects of foot traffic reduce turfgrass cover and increase soil bulk density, which can compromise both athletic field quality and safety. Losses of turfgrass cover and increases in soil bulk density can increase surface hardness (Gmax), which in turn increases athletes' likelihood of suffering a traumatic brain or lower extremity injury from exposure to excessive ground reaction force (Gadd, 1966; Gurdjian et al., 1966; Griffin et al., 2006). Harper et al. (1984) reported that 20% of the injuries suffered on a selection of high school football fields in central Pennsylvania were potentially related to poor field conditions and suggested that implementation of maintenance practices to maximize early-season turfgrass cover and reduce weed pressure could reduce athletes' injury risk.

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Many municipalities are restricting the use of pesticides (including herbicides) on athletic fields. In 2013, the Sports Turf Managers Association reported that 41 U.S. states restrict the use of pesticides on athletic fields, with several states prohibiting applications altogether (K. Heck, Sports Turf Managers Association CEO, personal communication, 2013). Legislation in Connecticut prevents the use of pesticides on public and private school athletic fields used by students in kindergarten through the eighth grade (Connecticut General Assembly, 2009). The state of New York has banned the use of pesticides on athletic fields at all public schools (New York State Department of Environmental Conservation, 2010). Similar legislation restricts pesticide use on athletic fields in several municipalities and provinces in Canada as well (Dévelopment durable, Environnement et Parcs, Québec, 2003; Ministry of Environment, 2011).

Restrictions on pesticide use may increase infestations of problematic weeds, such as large crabgrass (*Digitaria sanguinalis* L.) and white clover (*Trifolium repens* L.), on athletic fields as options for weed control without pesticides are only marginally effective. To that end, use of corn gluten meal has been researched as an alternative strategy for preemergence grassy weed control. Miller and Henderson (2012) observed more crabgrass (*Digitaria* spp.) on a Kentucky bluegrass (*Poa pratensis* L.) athletic field treated with four organic management programs incorporating the use of corn gluten meal at 588 kg ha^{-1} compared with a conventional program incorporating applications of the synthetic herbicides dithiopyr (202 kg ha^{-1}) and siduron (73 kg ha^{-1}). Fields treated with the conventional program also offered higher turfgrass quality and late-season color than organic regimes and retained greater cover under simulated traffic in a single year of the 2-yr study. However, no differences in soil bulk density, surface hardness, or rotational traction were detected between conventional and organic management programs. Christians (1993) reported up to 53% reduction in crabgrass populations following corn gluten meal applications at 990 kg ha^{-1}; however, this application would deliver approximately 98 kg N ha^{-1} to turf. Recently, St. John and Demuro (2013) reported that corn gluten meal applications at rates of 488 to 1952 kg ha^{-1} were no more effective in controlling smooth crabgrass (*Digitaria ischaemum* Schreb.) or common dandelion (*Taraxacum officinale* G.H. Weber) than urea or Milorganite (Milorganite, Milwaukee, WI) applied at similar N rates.

Overseeding is a common practice on athletic fields to help turf recover from traffic and to increase competition with weeds. Elford et al. (2008) and Miller and Henderson (2012) reported reductions in white clover, common dandelion, and crabgrass populations in Kentucky bluegrass research plots subjected to perennial ryegrass (*Lolium perenne* L.) overseeding, although these effects were not observed when overseeding was performed at similar rates at in-use soccer fields in Ontario (Elford et al., 2008).

Large crabgrass and white clover are common weeds on athletic fields (Puhalla et al., 1999). Data describing the playing quality of large crabgrass and white clover in response to simulated traffic are limited. Research on this topic is warranted considering that the presence of weeds on athletic fields has been associated with increased incidence of sports injuries, of which over 2.6 million children under the age of 19 receive medical treatment for annually (Harper et al., 1984; Safe Kids Worldwide, 2013). Thus, our objective was to evaluate the playing quality of large crabgrass and white clover compared with hybrid bermudagrass in response to simulated traffic. The null hypothesis was that large crabgrass and white clover would provide similar surface hardness and rotational traction following simulated athletic field traffic as hybrid bermudagrass.

MATERIALS AND METHODS

Plot Establishment

Field research was conducted during 2012 to 2013 at the University of Tennessee Center for Athletic Field Safety (Knoxville, TN) to evaluate the playing quality of large crabgrass and white clover compared with hybrid bermudagrass in response to simulated traffic. Sod was removed from an existing stand of Tifway hybrid bermudagrass on 27 Feb. 2012 to create plots (3 by 3 m) maintained as monostands of large crabgrass, white clover, or hybrid bermudagrass. Soil at this site is a Sequatchie silt loam (fine-loamy, siliceous, semiactive, thermic humic Hapludult), measuring 6.2 in soil pH and 25 g kg^{-1} in organic matter content. Additional soil was added to level areas where sod had been removed. Plots from which sod was removed were then seeded with large crabgrass (50 g m^{-2}) or white clover (10 g m^{-2}) on 30 Apr. 2012. Large crabgrass and white clover seed were purchased from commercial vendors (Azlin Seed Service. Leland, MS; Foothills Farmer's Co-op. Maryville, TN). Hybrid bermudagrass plots were not seeded with either species. A complete fertilizer (18N – 1.3 P – 15 K) was applied at 25 kg N ha^{-1} to plots seeded with large crabgrass. Similarly, large crabgrass plots also received supplemental phosphorus and potassium (0N – 8.7 P – 16.6 K) at a rate of 161 kg ha^{-1}. Since large crabgrass is an annual weed, plots were reseeded on 29 Apr. 2013 after all plots were core aerified with 13.4 mm hollow tines on a 5 by 5 cm spacing (ProCore 648. The Toro Company. Bloomington, MN). Overhead irrigation was applied to supplement rainfall to facilitate weed seed germination, establishment, and growth. Nutrients and seed were applied at the same rates in both years. White clover is a perennial weed and subsequently plots were not reseeded in 2013; plots recovered from underground rhizomes.

Plot Maintenance

After establishment, all plots were mowed three times per week with a triplex reel mower (TriKing 1900D; Jacobsen. Charlotte, NC) at 2.2 cm from May through October. Clippings were not collected and allowed to return to the surface during mowing. Plots established to white clover received no supplemental nutrition for the duration of the experiment. Sethoxydim (Select Herbicide. BASF Corporation. Research Triangle Park, NC) was applied four times throughout the growing season at 79 g ai ha^{-1} with a nonionic surfactant (Southern Agricultural Insecticides, Inc. Boone, NC) at 0.25% v/v to control grassy weeds infesting the white clover stand. Herbicide was applied as a spot treatment using a piston pump backpack sprayer (Solo 425. Solo, Inc. Newport News, VA) equipped with a single flat fan nozzle. Plots established to large crabgrass and hybrid bermudagrass received supplemental N from urea (46N-$0P_2O_5$- $0K_2O$) at 49 kg ha^{-1} monthly from May to September each year. Plots were irrigated immediately following urea application for a duration of 10 min. Additionally, hybrid bermudagrass plots received an application of oxadiazon (Ronstar 50WP; Bayer Environmental Sciences, Research Triangle Park, NC) at 3360 g ai ha^{-1} on 23 Feb. 2012 and 25 Feb. 2013. All plots received ~1 cm of irrigation within 24 h of oxadiazon applications to hybrid bermudagrass plots.

Simulated Traffic

All plots were subjected to simulated football game traffic using a Cady traffic simulator constructed similar to Henderson et al. (2005). Plots were subjected to 18 simulated traffic events from 21 Aug. to 26 Sept. 2012 and from 18 Aug. 2013 to 27 Sept. 2013. Traffic was applied at a rate of three events (i.e., six passes) per week. Two passes with the Cady traffic simulator has been shown to impart the same number of cleat marks (667 m^{-2}) as found after one National Football League game between the hashmarks at the 40-yard line (Henderson et al., 2005).

Data Collection

Green cover in each plot was quantified at the beginning of the study and after every simulated traffic event using digital images analysis (DIA) similar to Thoms et al. (2011). A 0.28 m^2 light box equipped with four 40w Spring Lamps (TCP, Lighthouse Supply Co., Bristol, VA) and powered by a Xantrex Power Pack (600 HD, Xantrex Technology, Vancouver, British Columbia) was used to capture digital images of each plot. Digital images were collected with a Canon (G5, Canon Inc., Japan) camera capable of capturing 5 million pixels per image. Total image size in this study was 307,200 pixels. SigmaScan Pro software (v. 5.0, SPSS Inc., Chicago, IL) used image pixelation measurements to calculate green cover according the methods of Richardson et al. (2001). Pixels defined as green cover had a hue range of 45 to 120° and saturation values between 0 and 100% The number of green pixels in each image was divided by the total number of pixels in the image to calculate green cover in each plot.

Surface hardness was measured after every simulated traffic event using a Clegg Soil Impact Tester (CIST, Lafayette Instrument Company, Lafayette, IN) equipped with a 2.25 kg missile and accelerometer. Surface hardness was measured as Gmax, a unitless number representing the ratio of maximum deceleration of the missile on impact, in units of gravities (G), relative to the acceleration due to gravity (American Society for Testing and Materials, 2000; Henderson et al., 1990). Methods were similar to Brosnan et al. (2009); however, means represented the average of seven subsamples from each plot.

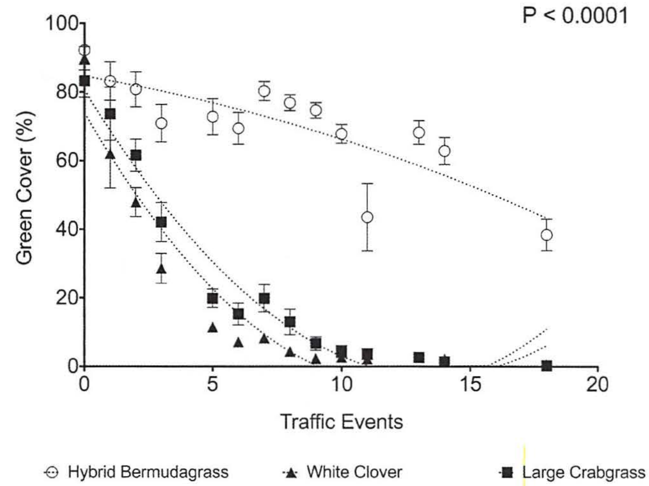

Figure 1. Changes in hybrid bermudagrass [*C. dactylon* (L.) Pers. · *C. transvaalensis* Burtt Davy], white clover (*Trifolium repens* L.), and large crabgrass (*Digitaria sanguinalis* L.) cover following 18 simulated traffic events during 2012 and 2013 in Knoxville, TN. Data from each year were combined for analysis. Standard error values are presented as a means of statistical comparison. Best-fit parameter estimates for nonlinear regression equations modeling responses are presented in Table 1.

Rotational resistance was measured using a studded disc apparatus similar to Canaway and Bell (1986). This device consisted of a steel disc (15 cm in diameter) fitted with studs commonly found on soccer shoes. The disc was fixed to a 90-cm long shaft loaded to 48 kg and dropped on the playing surface from a height of 6 cm. Torque required to tear the turfgrass (or large crabgrass or white clover) canopy was measured with a two-handled industrial torque wrench. Rotational resistance data were collected after 0, 9, and 18 simulated traffic events were applied each year, with means generated using data from seven subsamples per plot.

Statistical Analysis

The experiment was designed as a randomized complete block with three replications and repeated in time during 2012 and 2013. Green cover, surface hardness, and rotational resistance data were subjected to analysis of variance in SAS (v. 9.1, SAS Institute Inc., Cary, NC). No significant year · treatment interactions were detected in green cover data; therefore, data from each year were combined and analyzed using nonlinear regression techniques in GraphPad Prism 6 for Mac OS X (GraphPad Software, San Diego, CA). A sums of squares reduction F-test was conducted to compare sums of squares from a global model (all treatments shared the same parameter estimates) to a cumulative model where unique parameter estimates were calculated for each treatment.

Year · treatment interactions were present in surface hardness and rotational resistance data. Therefore, data from each year were analyzed and are presented separately. Fisher's least significant difference test was used to separate surface hardness and rotational resistance means at the $P = 0.05$ level. Pearson's correlation coefficients were also calculated to evaluate relationships between changes in green cover and surface hardness. Both procedures were conducted in SAS as well.

Table 1. Best-fit parameter estimates for regression equations characterizing changes in hybrid bermudagrass [*C. dactylon* (L.) Pers. · *C. transvaalensis* Burtt Davy], white clover (*Trifolium repens* L.), and large crabgrass (*Digitaria sanguinalis* L.) cover following 18 simulated traffic events during 2012 and 2013 in Knoxville, TN. Standard deviations for each parameter estimate are listed in parentheses.

Surface type†	β_0	β_1	β_2	R^2
Hybrid bermudagrass	84.59 (±3.52)	−1.25 (± 0.93)	−0.06 (± 0.05)	0.42
White clover	73.96 (± 2.90)	−12.86 (± 0.76)	0.52 (± 0.04)	0.85
Large crabgrass	80.65 (± 2.59)	−12.29 (± 0.68)	0.45 (±0.03)	0.88

† A sums of squares reduction *F*-test determined that the sums of squares from a global model (all treatments shared the same parameter estimates) was significantly different ($P < 0.0001$) from a cumulative model where unique parameter estimates were calculated for each treatment.

Table 2. Surface hardness values following application of 0, 6, 12, and 18 simulated traffic events to hybrid bermudagrass [*C. dactylon* (L.) Pers. · *C. transvaalensis* Burtt Davy], white clover (*Trifolium repens* L.), and large crabgrass (*Digitaria sanguinalis* L.) during 2012 and 2013 in Knoxville, TN.

	Surface hardness†,‡							
	2012				2013			
Surface type	0 events§	6 events	12 events	18 events	0 events	6 events	12 events	18 events
	Gmax							
Hybrid bermudagrass	48	69	61	68	47	66	64	56
White clover	97	134	120	134	64	117	146	115
Large crabgrass	92	121	120	130	61	125	153	125
$LSD_{0.05}$¶	4	8	8	8	4	9	8	7

† Surface hardness was measured with a Clegg Soil Impact Tester equipped with a 2.25 kg missile and accelerometer in units of Gmax. Means represented the average of seven subsamples from each plot.

‡ Volumetric soil moisture content was measured on each data that surface hardness data were collected using a time domain reflectometry (TDR) probe equipped with 5 cm tines in seven locations per plot. Volumetric soil moisture content averaged 34% during 2012 data collection and 37% in 2013.

§ Plots were subjected to 18 simulated traffic events from 21 Aug. to 26 Sept. 2012 and 18 Aug. 2013 to 27 Sept. 2013 at a rate of three events (i.e., six passes) per week.

¶ LSD, least significant difference.

RESULTS AND DISCUSSION

Green Cover

Quadratic equations fit green cover data collected on hybrid bermudagrass, large crabgrass, and white clover plots subjected to 18 simulated traffic events better than linear equations (Fig. 1). A sums-of-squares reduction *F*-test determined that parameter estimates for these quadratic equations were not shared among treatments ($P < 0.0001$). Therefore, unique parameter estimates for hybrid bermudagrass, large crabgrass, and white clover data are presented in Table 1 with standard error values included for statistical comparison.

Plots established to large crabgrass or white clover lost cover at a significantly higher rate than those established to hybrid bermudagrass in this study (Table 1). Slope (β_1) values for equations fitting large crabgrass and white clover green cover data were −12.29 and −12.81 compared with only −1.2 for hybrid bermudagrass. This response indicated that when subjected to simulated traffic, large crabgrass and white clover lost green cover approximately 12 times faster than hybrid bermudagrass. Harper et al. (1984) also reported a decrease in green cover on weed-infested high school football practice and game fields in Pennsylvania and surmised that the response was due to the poor traffic tolerance of weeds such as prostrate knotweed (*Polygonum aviculare* L.), crabgrass, goosegrass (*Eleusine indica* L.), and white clover.

Table 3. Rotational resistance values following application of 0, 9, and 18 simulated traffic events to hybrid bermudagrass [*C. dactylon* (L.) Pers. · *C. transvaalensis* Burtt Davy], white clover (*Trifolium repens* L.), and large crabgrass (*Digitaria sanguinalis* L.) during 2012 and 2013 in Knoxville, TN.

	Rotational resistance†					
	2012			2013		
Surface type	0 events‡	9 events	18 events	0 events	9 events	18 events
	Nm					
Hybrid bermudagrass	53	49	64	46	52	52
White clover	34	35	35	40	50	40
Large crabgrass	34	33	40	40	50	42
$LSD_{0.05}$§	4	4	4	3	NS	4

† Rotational resistance was measured using a studded disc apparatus similar to Canaway and Bell (1986). Means represented the average of seven subsamples from each plot.

‡ Plots were subjected to 18 simulated traffic events from 21 Aug. to 26 Sept. 2012 and 18 Aug. 2013 to 27 Sept. 2013 at a rate of three events (i.e., six passes) per week.

§ LSD, least significant difference.

Surface Hardness and Rotational Resistance

Surface hardness values varied due to treatment each year (Table 2). While few significant differences in surface hardness were detected between white clover and large crabgrass, values on hybrid bermudagrass were ~48 to 55% lower than those measured on either large crabgrass or white clover after 18 simulated traffic events were applied. Rotational resistance values in this research were greater on hybrid bermudagrass than either white clover or large crabgrass (Table 3). Rotational resistance is important for sufficient traction to allow athletes to complete a turn during games without slipping. While a universally accepted range of rotational resistance values for desired footing does not exist, the relative lack of rotational resistance on white clover and large crabgrass indicates slippage would be expected to a degree that play or player safety could be affected.

Changes in surface hardness and rotational resistance may be the result of hybrid bermudagrass plots retaining greater cover under simulated traffic as changes in both surface hardness and rotational resistance were significantly correlated ($P < 0.0001$) to changes in green cover. Goddard et al. (2008) also reported lower surface hardness values on several bermudagrass cultivars retaining greater green cover after receiving crumb rubber topdressing before simulated traffic. Rogers et al. (1988) reported higher surface hardness values on more heavily trafficked portions of high school football fields (i.e., in between the hash marks) than on areas receiving less traffic. The researchers attributed the response to differences in turf cover, soil moisture content, and soil compaction. Henderson et al. (1990) measured higher surface hardness values on bare soil than Kentucky bluegrass. In the current study, no green cover was remaining on large crabgrass or white clover plots subjected to simulated traffic; surface hardness values on those surfaces ranged from 115 to 134 Gmax compared with 56 to 68 Gmax for hybrid bermudagrass retaining 40% green cover after trafficking (Table 2, Fig. 1).

Implications for Athletic Field Managers

Under the conditions of this study, large crabgrass or white clover offered reduced athletic field playing quality compared with hybrid bermudagrass. These surfaces comprised of weeds lost green cover nearly 12 times faster than those maintained as monostands of hybrid bermudagrass. This loss of cover not only reduced aesthetic quality (data not shown) but also facilitated the increases in surface hardness observed in each year of our study. This response is concerning given that incidence of both lower extremity and head injuries has been associated with increased surface hardness (Gadd, 1966; Gurdjian et al., 1966; Griffin et al., 2006). In addition, we found that 10 simulated traffic events reduced ground cover to nearly zero for the white clover and large crabgrass treatments. Such an extensive loss of ground cover would likely lead to soil displacement and erosion, adding financial costs for surface reconstruction to keep fields playable. Our findings would suggest that weed management is critical to maintaining ground cover on athletic fields. Weed management may be accomplished in various ways, including sufficient fertilization, irrigation, and overseeding. In many cases, herbicide applications for large crabgrass and white clover control would also be a viable means of improving the aesthetic quality and safety of hybrid bermudagrass athletic fields.

A limitation of this research is that plots were managed as monostands of hybrid bermudagrass, large crabgrass, or white clover. Deleterious effects on athletic field playing quality may have been less pronounced on polystands of hybrid bermudagrass and the two weed species studied. For example, Miller and Henderson (2012) observed greater natural infestations of crabgrass in organically managed Kentucky bluegrass that only resulted in reduced green cover following simulated traffic in a single year of a 2-yr study. Future research is needed to evaluate athletic field playing quality on polystands of hybrid bermudagrass, large crabgrass, and white clover. Information of this nature could facilitate the development of weed infestation thresholds warranting herbicide applications.

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References

American Society for Testing and Materials. 2000. Annual book of standards. Vol. 15.07. End use products. Standard test method for shock-attenuation characteristics of natural playing surface systems using a lightweight portable apparatus. F1702–96. American Society for Testing and Materials, West Conshohocken, PA.

Brosnan, J.T., A.S. McNitt, and T.J. Serensits. 2009. Effects of varying surface characteristics on the hardness and traction of baseball field playing surfaces. Int. Turf. Soc. Res. J. 11:1053–1065.

Canaway, P.M., and S.W. Baker. 1993. Soil and turf properties governing playing quality. Int. Turf. Soc. Res. J. 7:192–200.

Canaway, P.M., and M.J. Bell. 1986. Technical note: An apparatus for measuring traction and friction on natural and artificial playing surfaces. J. Sports Turf. Res. Inst. 62:211–214.

Carrow, R.N., and A.M. Petrovic. 1992. Effects of traffic on turfgrass. In: D.V. Waddington, R.N. Carrow, and R.C. Shearman, editors, Turfgrass. Agron. Monogr. 32. ASA, CSSA, and SSSA, Madison, WI. p. 285–330.

Christians, N.E. 1993. The use of corn gluten meal as a natural preemergence weed control in turf. Int. Turf. Soc. Res. J. 7:284–290.

Connecticut General Assembly. 2009. Substitute Senate Bill No. 1020. Public Act No. 09–56. An act concerning pesticide applications at child day care centers and schools. Office of Legislative Management, Hartford, CT. www.cga.ct.gov/2009/act/Pa/pdf/2009PA-00056–R00SB-01020-PA.PDF (accessed 6 Sep. 2013).

Dévelopment durable, Environnement et Parcs, Québec. 2003. The pesticides management code. Gouvernement du

Québec, Québec, Canada. www.mddep.gouv.qc.ca/pesticides/permis-en/code-gestion-en/index.htm (accessed 6 Sep. 2013).

Elford, E.M.A., F.J. Tardif, D.E. Robinson, and E.M. Lyons. 2008. Effect of perennial ryegrass overseeding on weed suppression and sward composition. Weed Technol. 22:231–239. doi:10.1614/WT-07-120.1

Gadd, C.W. 1966. Use of a weighted impulse criterion for estimating injury hazard. In Proceedings of the 10th Stapp Car Crash Conference, Hollomon Air Force Base, NM. 8–9 Nov. 1966. SAE, New York. p. 164–174.

Goddard, M.J., J.C. Sorochan, J.S. McElroy, D.E. Karcher, and J.W. Landreth. 2008. The effects of crumb rubber topdressing on hybrid Kentucky bluegrass and bermudagrass athletic fields in the transition zone. Crop Sci. 48:2003–2009. doi:10.2135/cropsci2007.07.0405

Griffin, L.Y., M.J. Albohm, E.A. Arendt, R. Bahr, B.D. Beynnon, M. DeMaio, et al. 2006. Understanding and preventing noncontact anterior cruciate ligament injuries: A review of the Hunt Valley II meeting, January 2005. Am. J. Sports Med. 34:1512–1532. doi:10.1177/0363546506286866

Gurdjian, E.S., V.L. Roberts, and L.M. Thomas. 1966. Tolerance curves of acceleration and intracranial pressures and protective index in experimental head injury. J. Trauma 6:600–604. doi:10.1097/00005373-196609000-00005

Harper, J.C., C.A. Morehouse, D.V. Waddington, and W.E. Buckley. 1984. Turf management, athletic field conditions, and injuries in high school football. Pennsylvania Agri. Exp. Stn. Prog. Rep. 384. Pennsylvania State Univ., University Park, PA.

Haselbauer, W.D., A.W. Thoms, J.C. Sorochan, J.T. Brosnan, B.M. Schwartz, and W.W. Hanna. 2012. Evaluation of experimental bermudagrasses under simulated athletic field traffic with perennial ryegrass overseeding. Horttechnology 22:94–98.

Henderson, J.J., J.L. Lanovaz, J.N. Rogers, III, J.C. Sorochan, and J.T. Vanini. 2005. A new apparatus to simulate athletic field traffic: The Cady traffic simulator. Agron. J. 97:1153–1157. doi:10.2134/agronj2004.0083

Henderson, R.L., D.V. Waddington, and C.A. Morehouse. 1990. Laboratory measurements of impact absorption on turfgrass and soil surfaces. In: R.C. Schmidt et al., editors, Natural and artificial playing fields: Characteristics and safety features. American society for testing and materials. Spec. Tech. Publ. 1073. American Society for Testing Materials, West Conshohocken, PA. p. 127–135.

Miller, N.A., and J.J. Henderson. 2012. Organic management practices on athletic fields: Part 1. The effects on color, quality, cover, and weed populations. Crop Sci. 52:890–903. doi:10.2135/cropsci2011.07.0359

Ministry of Environment. 2011. Pesticides Act and Ontario Regulation 63/09: Specialty turf and specified sports fields. Ministry of the Environment. Toronto, Ontario, Canada. www.ene.gov.on.ca/stdprodconsume/groups/lr/@ene/@resources/documents/resource/stdprod_080151.pdf (accessed 6 Sep. 2013).

New York State Department of Environmental Conservation. 2010. Guidance on Chapter 85, Laws of 2010: Summary of pesticide prohibition requirements and pesticide alternatives regarding schools and day care centers in New York State. New York State Department of Environmental Conservation, Albany, NY. http://ocfs.ny.gov/main/childcare/DCC%20Guidance%20for%20Pesticide%20ban%20Chapter%2085.pdf (accessed 6 September 2013).

Puhalla, J., J. Krans, and M. Goatley. 1999. Sports fields: A manual for design, construction, and maintenance. John Wiley & Sons, Hoboken, NJ.

Richardson, M.D., D.E. Karcher, and L.C. Purcell. 2001. Quantifying turfgrass cover using digital image analysis. Crop Sci. 41:1884–1888. doi:10.2135/cropsci2001.1884

Rogers, J.N., III, D.V. Waddington, and J.C. Harper, II. 1988. Relationships between athletic field hardness, traction, vegetation, soil properties, and maintenance practices. Penn. Agric. Exp. Station. Prog. Rep. 393. Pennsylvania State Univ., University Park, PA. p. 1–15.

Safe Kids Worldwide. 2013. Sports and recreation safety fact sheet. www.safekids.org/sites/default/files/documents/2013%20Sports.pdf (accessed 6 Sep. 2013).

St. John, R., and N. Demuro. 2013. Efficacy of corn gluten meal for common dandelion and smooth crabgrass control compared to nitrogen fertilizers. Appl. Turf. Sci. doi:10.1094/ATS-2013-0426-01-RS

Thoms, A.W., J.C. Sorochan, J.T. Brosnan, and T.J. Samples. 2011. Perennial ryegrass (*Lolium perenne* L.) and grooming affect bermudagrass traffic tolerance. Crop Sci. 51:2204–2211. doi:10.2135/cropsci2010.08.0489

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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.

Core Ideas

1. Managed turfgrass confers many positive societal and environmental benefits.

2. These ecosystem services are predicated on sites receiving appropriate management resources.

3. Resource allocation in the COVID-19 era should be structured to achieve these benefits.

A Justification for Continued Management of Turfgrass During Economic Contraction

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ABSTRACT

A novel coronavirus, termed COVID-19, spread worldwide and become a global pandemic in 2020. Forecasts show that COVID-19 will cause substantial economic contraction affecting almost every industry. Managed turfgrass, particularly in urban settings, has many positive societal and environmental benefits. In a contracted economy, will resources be available to manage turfgrass to achieve these benefits? In this paper, we outline the benefits of managed turfgrass on golf courses, playing fields, recreational parks, and urban landscapes to assist decision makers with resource allocation in the COVID-19 era.

INTRODUCTION

A novel coronavirus, termed COVID-19 by the World Health Organization, rapidly spread worldwide and become a global pandemic (Sohrabi et al., 2020). By August 4th, 2020 there were nearly 18.1 million confirmed cases worldwide, including 4.6 million in the United States (US) leading to more than 154,000 deaths (WHO 2020). Travel bans, enforced quarantines, school closures, and social distancing practices were implemented to limit spread of COVID-19 (Parmet and Sinha, 2020; Sohrabi et al., 2020). The National Bureau of Economics Research estimates that COVID-19 will lead to a 20% contraction of the US economy by the end of the fiscal year with effects continuing into the future as businesses reduce expenditures related to innovation, training, and general management (Baker et al., 2020).

Nearly every industry has been affected by COVID-19, including turfgrass management. In addition to the cancellation of professional and collegiate sports played on turfgrass surfaces (PGA Tour, MLB, MLS, and NCAA), COVID-19 led to the temporary closure of all golf courses in 19 states (NGF 2020) as well as municipal parks and recreational fields across the US. In some states lawn care and outdoor activities were restricted or inhibited (State of Michigan, 2020; State of Oregon, 2020). Many facilities have furloughed staff and it remains uncertain if financial resources will be available to fill these positions in the future. A federal order facilitated the landscape industry to maintain normal staffing during the pandemic (Krebs, 2020) but this may change with the forthcoming downturn of the economy.

COVID-induced economic uncertainty will have a major effect on all facets of agriculture for the foreseeable future (Lusk et al., 2020). It is well established that managed turfgrass, particularly in urban settings, offers many societal and environmental benefits. In a contracted economy, will resources be available to manage turfgrass to achieve these benefits? Our objective is to outline the benefits of managed turfgrass on golf courses, playing fields, recreational parks, and urban landscapes to assist decision makers with resource allocation in the COVID-19 era.

BENEFITS OF TURFGRASS

Turfgrasses ameliorate the impacts of urban sprawl in today's rapidly urbanizing global society, and offer many environmental benefits documented by several authors and summarized by Beard and Green (1994), Stier et al. (2013), and Christians et al. (2017). Benefits include temperature moderation through evaporative cooling resulting in dissipation of radiant heat and mitigation of the heat island effect in cities (Amani-Beni et al., 2018; Jenerette et al., 2011; Wang et al., 2016b). Maximum daily canopy temperature of a green, growing turfgrass was found to be 21°C cooler than a brown, dormant, sward and 39 °C cooler than synthetic turf (Beard and Johns, 1985). The transpirational cooling effect of green turfgrass can reduce energy input and costs required for indoor cooling (Beard and Beard, 1985). Turfgrasses also play an important role in stabilizing soils in urban centers, underutilized, and abandoned properties (Montgomery, et al, 2016); reducing surface water runoff thereby recharging groundwater and reducing soil and water erosion (Bouwer, 2002; Dai et al., 2016); absorbing atmospheric pollutants (greenhouse gases) produced through anthropogenic activities, especially in densely populated regions (Thwaites et al., 2006), sequestering carbon (Law and Patton, 2017; Braun and Bremer, 2019; Hamido et al., 2016; Qian and Follett, 2002), producing oxygen and improving air quality (Monteiro, 2017); reducing noise pollution (Van Renterghem et al., 2015); and decontaminating soils through phytoremediation and associated plant-microbe interactions (Crouch et al., 2017; Grant et al. 2002; Krishnan et al., 2000; Lin et al., 2004; Shahandeh and Hossner, 2000; Thompson et al., 2008; Tordoff, 2000).

Turfgrasses also impact the lives of people by improving their physical and mental health, and social well-being. Greenspace, which includes healthy lawns and landscapes, is inversely related to the incidence of crime, especially in inner-city neighborhoods (Kuo et al., 1998; Kuo and Sullivan, 2001). A well-managed lawn with healthy turfgrass, trees, and ornamental plants increases property value by improving perceptions of residential communities, businesses, and schools (Laverne and Winsin-Geideman, 2003; Stier et al., 2013). Greenspace will provide communities with accessible and safe environments to exercise, socialize, and overcome activity restriction in the COVID-19 era. Turfgrass and associated greenspace enhance the creative, intellectual and cognitive skills of children (Frumkin, 2001; Heerwagen and Orians, 2002; Kahn and Kellert, 2002) and provide safe playing surfaces for athletes (Mack et al., 2019). According to the Center for Disease Control and Prevention, people with close access to parks and trails are more likely to lead a more physically active lifestyle and therefore, have reduced risk of chronic diseases (CDC, 2014; Barrett 2014) and lower body mass index (BMI) (Liu et al., 2007; Bell et al., 2008). Decreased mortality rates have been documented among those living in areas with increased greenspace (James et al., 2016). In addition to physical health benefits, turfgrasses also offer many mental health benefits (Moore, 1981). Proximity to greenspace and connection with nature provides a sense of tranquility (Frumkin, 2001) and has been associated with reducing stress and symptoms of depression (Beyer et al., 2014; Barrett 2014); conditions likely to rise in response to COVID-19 (Gao et al., 2020). Increased participation in outdoor activities has been documented in the COVID-19 era (Venter et al., 2020), in part because exposure risks are lower outdoors (Ratnesar-Shumate et al., 2020). Turfgrasses also provide a sense of communal space for neighborhood gatherings and community events, which helps improve social ties, community pride, and overall quality of life (Hartig et al., 2014).

Golf Courses– Environmental benefits of golf courses include flood control and groundwater recharge of filtered water when absorbing surface flows from residential areas (Bouwer, 2002; Dai et al., 2016). Biodiversity and abundance of wildlife and insects are maintained as many golf courses provide the minimum size necessary for multiple species, which is critical as populations decline globally (Beninde et al., 2015; Tanner and Gange, 2005; van Klink et al., 2020). Golf course rough and non-play areas make up 60 to 70% of most golf courses and often consist of conservatively managed grasses, trees and shrubs. When combined with the open areas of fairways and greens, this greenspace creates viable wildlife habitat (Cohn, 2008). Golf courses, like parks and forests, reduce the urban heat island effect; in Los Angeles, CA temperatures on the golf course were ~ 4°C cooler than the urban surroundings (Davis et al., 2016; Dousset and Gourmelon, 2003). In Colorado, well-managed golf courses fairways were found to have twice as much soil carbon, up to about 80 Mg ha^{-1}, as the native prairie

(Bandaranayake et al., 2003). Golf courses can be built on reclaimed landfills providing positive environmental and social benefits (Sharma et al. 2007; Deegan, 2017).

Social benefits include the physical and mental health accrued through both playing the game of golf and the relaxation provided by being in nature, which has been shown to increase life expectancy (Barton et al., 2009; Farahmand et al., 2009; Stenner et al., 2016). Two-thirds of U.S. states deemed golf courses as "essential services" during the 2020 COVID-19 pandemic (Kelleher, 2020). Golf courses add ≥ 25% property value to homes depending on proximity (Nicholls and Crompton, 2007). The golf industry employs approximately 2 million people, with economic impact of nearly $180 billion (SRI, 2012). Golf courses consistently serve as fundraising venues, raising about $4 million annually in the U.S. (NGF, 2017).

Playing Fields- As the majority of turfgrass playing surfaces exist in urban environments, the World Health Organization (WHO) suggested that the availability, accessibility, quality, and security of public green spaces is an indicator of a healthy city (WHO, 2012). The provision, regulating, and supporting ecosystem services provided by turfgrass playing surfaces are consistent with large managed natural vegetative surfaces in urban environments (Thompson and Kao-Kniffen, 2017). Therefore, the ecosystem services provided by turfgrass playing surfaces could be explained by the preference of humans for turfgrass environments and the restorative value of organized play.

Running in a park is associated with a more restorative experience when compared to the same exercise in an urban environment (Bodin and Hartig, 2003). Bagot et al. (2014) reported that turfgrass playing fields were preferred over synthetic surfaces. Findlay and Copeland (2008) found that organized play was positively related to indices of positive adjustment and plays a unique protective role for shy children by reducing anxiety. Flouri et al. (2014) found that poor children in urban areas with more turfgrass playing fields had fewer emotional problems from age 3 to 5 than their counterparts in areas with fewer turfgrass fields. To maximize ecosystem services, turfgrass playing fields should be managed to meet safety standards outlined in ASTM F-2269 and ASTM F-2060 (ASTM, 2018). Safety standards assure proper care and management of turfgrass playing surfaces. Pest management is of particular concern on sports fields as failure to control infestations reduces safety to end-users (Brosnan et al., 2014; Bartholomew et al., 2015).

Parks and Recreation - Parks and recreational areas are dominated by turfgrass (Ignatieva et al., 2017; Wheeler et al., 2017). These areas provide a variety of social, economic, and environmental benefits. The social benefits of these public areas include improved health and safer environments (Barnes et al., 2018; Demuzere et al., 2014; Dyment and Bell, 2008; Monteiro, 2017; Sadler et al., 2017). Managed turfgrass in parks serve some of the largest user groups, employ a significant number of people, and produce a substantial economic impact (Diemer 2004; English et al., 2015; Hodges et. al, 1994; Kane and Wolfe, 2012). Municipal turfgrass areas typically receive less intensive cultural inputs and are managed with little or no pesticides (Barnes et al., 2018; Dernoeden et al., 1994; Diesburg et al., 1997; Kowalewski et al., 2016; Kowalewski et al., 2014; Patton et al., 2017; Watkins et al., 2014). Municipal turfgrass areas also serve as disposal sites for municipal waste. For example, effluent wastewater is used as an effective alternative to potable water to maintain turfgrass (Alshammary and Qian, 2008; Hayes et al., 1990; Hyde, 1937; Mancino and Pepper, 1992; Miyamoto and Chacon, 2004; Riper and Geselbracht, 2020; Wang et al., 2014). Several cities actively promote mulching tree leaves and redistributing leaf mulch as a soil amendment that improves turfgrass health (City of Madison, 2020; City of Irving, 2020; City of Raleigh, 2020; Kowalewski et al., 2010). These waste products offer low cost irrigation and fertilizer alternatives that are readily available to public municipalities (Riper and Geselbracht, 2020; Heckman and Kluchinski, 1996).

Lawn and Landscape- Urban vegetation and greenspaces play a crucial role in creating a comfortable living environment, particularly in semi-arid and arid climates. A study conducted in Phoenix, AZ documented nearly 25°C surface cooling on turfgrass compared to bare soil (Jenerette et al., 2011). Cooling from urban lawns via evapotranspiration plays a significant role in lowering surrounding surface temperatures thereby positively affecting human thermal comfort and reducing energy consumption associated with air conditioning (Wang et al., 2016b). Amani-Beni et al. (2018) suggested increasing turfgrass coverage grown in conjunction with trees and focusing on irrigation management in order to maximize the cooling effect of urban parks.

Numerous authors have established a positive relationship between greenspaces and the well-being of residents. The restorative effect of greenspaces on humans and associated impacts on human health have been documented (Akpinar, 2016; Wells and Rollings, 2012). Akpinar et al. (2016) reported that more urban greenspace was associated with fewer days of mental health complaints in urban areas. Studies also demonstrated that greenspaces in schoolyards had a higher positive restorative effect on children (Bagot et al., 2015, Kelz et al., 2015). Ward et al. (2016) and Benjamin-Neelon et al. (2019) confirmed that greenspace exposure was positively associated with physical activity in children aged 3 to 14 years. Significant associations between childhood obesity and the distance between the child's residence and greenspace have been reported (Manandhar et al., 2019; Shradda et al., 2019) with expansion of green areas thought to prevent weight gain at early ages.

Elam and Stigarll (2012) estimated a 17% increase in residential house pricing when landscape quality is improved. Conway et al. (2010) documented a significant impact on house prices if homes are near a greenspace. They calculated that a 1% increase in greenspace within 200 to 300 ft of the residence would result in an approximate increase of 0.07% in the expected sales price. They further suggested that greening of inner city areas could provide a valuable policy instrument for elevating depressed housing markets.

Studies have shown that lawns act as a net carbon sink (Law and Patton, 2017; Braun and Bremer, 2019; Hamido et al., 2016) and sequester carbon into the organic pool at similar levels to other grassland soils (Braun and Bremer, 2019). Wang et al. (2016a) documented that organic carbon sharply increased in desert soils after desert shrubs were converted to irrigated lawn. Similarly, soil inorganic carbon doubled in six years in the turfgrass soil after conversion from desert shrubs.

CONCLUSION

The aforementioned ecosystem services provided by greenspaces containing turfgrass (i.e., golf courses, playing fields, parks and recreation, and lawn and landscapes) are predicated on the sites receiving appropriate resources for management. In the absence of allocable resources, these greenspaces will deteriorate leading to concomitant reductions in aesthetics, function, and recreational quality. Turfgrass management encompasses a range of activities including cultural practices (e.g., mowing, fertilization, irrigation, cultivation, and pest management) for establishing and sustaining sites at a desired level of quality.

Although budget reductions are a likely reality of COVID-19, prioritization of expenditures is necessary and essential minimums should focus on the three primary cultural practices: mowing, fertilization, and irrigation. Mowing is the most basic practice needed to provide desirable turfgrass. Second, turfgrasses, like all living organisms, require nutrition. Nutrition for greenspaces primarily comes in the form of fertilizer and other practices to maintain soil health such as cultivation and liming. Third, all plants, including turfgrasses, require water to sustain life. Irrigation resources should supplement natural rainfall allowing these greenspaces to remain productive.

In an era of COVID-19 related budget constraints, decision makers should work with facility managers and stakeholders to identify essential minimums to ensure that realistic expectations for greenspaces are achieved while mitigating negative impacts on ecosystem services. For example, non-prioritized reductions in spending on golf course management will result in poor playing conditions further resulting in potential revenue loss as golfers seek other venues. The cascading effect can lead to the demise of a golf course and resultant loss of valuable greenspace nestled into urban and suburban development. Similarly, insufficient resource allocation to playing fields, parks, and recreational areas can yield unsafe conditions exposing municipalities to increased liability. Unkept and neglected landscapes are associated with higher rates of crime (Troy et al., 2016). Neglect of these greenspaces or eliminating their inputs altogether, is not advisable.

REFERENCES

Akpinar, A. 2016. How is high school greenness related to students' restoration and health? Urban Forestry & Urban Greening. 16:1-8.

Akpinar, A., C. Barbosa-Leiker, and K.R. Brooks. 2016. Does green space matter? Exploring relationships between green space type and health indicators. Urban Forestry & Urban Greening 20: 407-418.

Alshammary, S.F. and Y.L. Qian. 2008. Long term effects of effluent water irrigation on soil nitrate and phosphorus profiles under turfgrass. J. of Applied Science. 8:3662-3668.

Amani-Beni, M., B. Zhang, X. Gao-di, and X. Jie. 2018. Impact of urban park's tree, grass and waterbody on microclimate in hot summer days: A case study of Olympic Park in Beijing, China. 2018. Urban Forestry & Urban Greening 32:1-6.

ASTM F2269-11. 2018. Standard Guide for Maintaining Warm Season Turfgrasses on Athletic Fields, ASTM International, West Conshohocken, PA. www.astm.org

ASTM F2060-00. 2018. Standard Guide for Maintaining Cool Season Turfgrasses on Athletic Fields, ASTM International, West Conshohocken, PA. www.astm.org

Bagot, K.L., F.C. Louise Allen, and S. Toukhsati. 2015. Perceived restorativeness of children's school playground environments: nature, playground features and play period experiences. J. Environ. Psychol. 41:1–9.

Baker, S.R., N. Bloom, S.J. Davis, and S.J. Terry (2020) COVID-Induced Economic Uncertainty. National Bureau of Economics Research Working Paper No. 26983 doi: 10.3386/w26983.

Bandaranayake, W., Y.L. Qian, W.J. Parton, D.S. Ojima, and R.F. Follett. 2003. Estimation of soil organic carbon changes in turfgrass systems using the CENTURY model. Agron. J. 95:558-563.

Barnes, M.R., K.C. Nelson, A.J. Meyer, E. Watkins, S.A. Bonos, B.P. Horganc, W.A. Meyer, J. Murphy, and C. Yue. 2018. Public land managers and sustainable urban vegetation: the case of low-input turfgrasses. Urban Forestry and Urban Greening. 29:284-292.

Barrett, M.A., D. Miller, H. Frumkin. 2014. Parks and Health: Aligning Incentives to Create Innovations in Chronic Disease Prevention. Prev Chronic Dis 2014;11:130407. DOI: http://dx.doi.org/10.5888/pcd11.130407

Bartholomew, C., B.L. Campbell, and V. Wallace. 2015. Factors affecting school grounds and athletic field quality after pesticide bans: The case of Connecticut. HortSci. 50:99-103.

Barton, J., R. Hine, and J. Pretty. 2009. The health benefits of walking in greenspaces of high natural and heritage value. J. Integrative Environmental Sciences. 6:261-278.

Beard, J.B. and R.L. Green. 1994. The role of turfgrasses in environmental protection and their benefits to humans. J. Environ. Qual. 23:452–460.

Beard, J.B. and D. Johns. 1985. The comparative heat dissipation from three typical urban surfaces: asphalt, concrete, and bermudagrass turf. p. 125-133. *In* Texas turfgrass res-1985. Texas Agric. Exp. Stn. PR-4329. College Station.

Bell, J.F., J.S. Wilson, and G.C. Liu. 2008. Neighborhood greenness and 2-year changes in body mass index of children and youth. Amer. J. Preventive Med. 35:547-533.

Beninde, J., M. Veith, and A. Hochkirch. 2015. Biodiversity in cities needs space: a meta-analysis of factors determining intra-urban biodiversity variation. Ecol. Letters 18:581-592.

Benjamin-Neelon, S.E., A. Platt, M. Bacardi-Gascon, S. Armstrong, B. Neelon, and A. Jimenez-Cruz. 2019. Greenspace, physical activity, and BMI in children from two cities in northern Mexico. Preventive Medicine Reports 14: 100870. doi: 10.1016/j.pmedr.2019.100870

Beyer, K.M.M., A. Kaltenbach, A. Szabo, S. Bogar, F.J. Nieto, and K.M. Malecki. 2014. Exposure to neighborhood green space and mental health: evidence from the survey of the health of Wisconsin. Int. J. Environ. Res. Public Health. 11:3453-3472.

Braun, R.C. and D.J. Bremer. 2019. Carbon sequestration in zoysiagrass turf under different irrigation and fertilization management regimes. Agrosystems, Geosciences & Environment 2:1–8. https://doi.org/10.2134/age2018.12.0060

Brosnan, J.T., K.H. Dickson, J.C. Sorochan, A.W. Thoms, and J.C. Stier. 2014. Large crabgrass, white clover, and hybrid bermudagrass athletic field playing quality in response to simulated traffic. Crop Sci. 54:1838-1843.

Bodin, M. and T. Hartig. 2003. Does the outdoor environment matter for psychological restoration gained through running? Psychology of Sport and Exercise, 4, 141-153.

Bouwer, H. 2002. Integrated water management for the 21st century: Problems and solutions. J. Irrigation and Drainage Engineering. 128:193-202.

Center for Disease Control and Prevention (CDC). 2014. Healthy places: parks, trails, and health. Retrieved June 14, 2020. https://www.cdc.gov/healthyplaces/healthtopics/parks.htm

Christians, N.E., A.J. Patton, and Q.D. Law. 2017. Fundamentals of Turfgrass Management. John Wiley and Sons, New Jersey. p. 470.

City of Raleigh. 2020. Yard Waste Center. Raleight, NC. Retrieved May 28, 2020. https://raleighnc.gov/services/content/SolidWaste/Articles/YardWasteRecyclingCen.html

City of Irving. 2020. Leaf Management. Irving, Texas. Retrieved May 28, 2020. https://www.cityofirving.org/614/Leaf-Management

City of Madison. 2020. Make Leaf Mulch. Madison, Wisconsin. Retrieved May 28, 2020. https://www.cityofmadison.com/streets/LeaveTheLeaf/mulch.cfm

Cohn, J.P. 2008. Wildlife scores on golf courses. BioScience. 58: 568. https://doi.org/10.1641/B580617

Conway, D., C.Q. Li, J. Wolch, C. Kahle, and M. Jerrett. 2010. A spatial autocorrelation approach for examining the effects of urban greenspace on residential property values. Journal of Real Estate Finance and Economics 41(2). p. 150-169. https://doi.org/10.1007/s11146-008-9159-6

Crouch, J. A., Z. Carter, A. Ismaiel, and J.A. Roberts. 2017. The US National Mall microbiome: a census of rhizosphere bacteria inhabiting landscape turf. Crop Sci. 57(Suppl1):S-341-S-348. doi:10.2135/cropsci2016.10.0849

Dai, Z., X. Puyang, and L. Han. 2016. Using assessment of net ecosystem services to promote sustainability of golf course in China. Ecological Indicators 63:165-171.

Davis, A.Y., J. Jung, B.C. Pijanowski, and E.S. Minor. 2016. Combined vegetation volume and "greenness" affect urban air temperature. Applied Geography. 71:106-114.

Deegan, J.S. 2017. Grass over garbage: Golf courses give landfill sites a second life. Retrieved June 7, 2020. https://www.golfadvisor.com/articles/grass-over-garbage-golf-courses-give-landfill-sites-a-second-life

Demuzere, M., K. Orru, O. Heidrich, E. Olazabal, D. Geneletti, H. Orru, A.G. Bhave, N. Mittal, E. Feliu, and M. Faehnle. 2014. Mitigating and adapting to climate change: Multi-functional and multi-scale assessment of green urban infrastructure. Journal of Environmental Management. 146:107-115.

Dernoeden, P.H., M.J. Carroll, and J.M. Krouse. 1994. Mowing of three fescue species for low-maintenance turf sites. Crop Science. 34:1645–1649.

Diesburg, K.L., N.E. Christians, R. Moore, B. Branham, T.K. Danneberger, Z. Reicher, T.B. Voigt, D.D. Minner and R. Newman. 1997. Species for Low-input Sustainable Turf in the U.S Upper Midwest. Agronomy Journal. 89:690–696.

Diemer, J. Economic Impact: Golf and Tufgrass in New Mexico 2004-2005. Department of Economics and Agricultural Business, New Mexico State University, Las Cruces, New Mexico. Pages 1-36.

Dousset, B. and F. Gourmelon. 2003. Satellite multi-sensor data analysis of urban surface temperatures and landcover. J. Photogrammetry and Remote Sensing 58:43-54.

Dyment, J.E. and A.C. Bell. 2008. Grounds for movement: green school grounds as sites for promoting physical activity. Health Education Research. 23:952-962.

Emmett E. and A. Stigarll. 2012. Landscape and house appearance impacts on the price of single-family houses. J. Environ. Hort. 30:182–188. doi: https://doi.org/10.24266/0738-2898.30.4.182

English, B.C., J. Menard, K. Jensen, J.T. Brosnan, and C. Boyer. 2015. Tennessee's Turfgrass Industry: Economic Contributions, Problematic Issues, and Perceptions of Future Growth, 2015. Agri-Industry Modeling and Analysis Group, University of Tennessee, Knoxville, Tennessee. Pages 1-95.

Farahmand, B., G. Broman, U. De Faire, D. Vågerö, and A. Ahlbom. 2009. Golf: a game of life and death–reduced mortality in Swedish golf players. Scandinavian J. Med. & Sci in Sports. 19: 419-424.

Findlay, L. and R.J. Coplan. 2008. Come out and play: shyness in childhood and the benefits of organized sports participation. Canadian Journal of Behavioural Science Vol. 40(3): 153–161.

Flouri, E., E. Midouhas, and H. Joshi. 2014. The role of urban neighbourhood green space in children's emotional and behavioural resilience. Journal of Environmental Psychology 40: 179-186. https://doi.org/10.1016/j.jenvp.2014.06.007

Frumkin, H. 2001. Beyond toxicity: Human health and the natural environment. Am. J. Prev. Med. 20:234–240. doi:10.1016/S0749-3797(00)00317-2.

Gao J, P. Zheng, Y. Jia, H. Chen, Y. Mao, S. Chen, Y. Wang, H. Fu, and J. Dai. 2020. Mental health problems and social media exposure during COVID-19 outbreak. PLoS ONE 15(4): e0231924. https://doi.org/10.1371/journal.pone.0231924.

Grant, C.D., C.J. Campbell, and N.R. Charnock. 2002. Selection of species suitable for derelict mine site rehabilitation in New South Wales, Australia. Water Air Soil Pollut. 139:215–235. doi:10.1023/A:1015860025136

Hamido, S.A., E.A. Guertal, and C.W. Wood. 2016. Carbon sequestration under warm season turfgrasses in home lawns. Journal of Geoscience and Environment Protection 9: 53-63. DOI: 10.4236/gep.2016.49005

Hartig T, Mitchell R, de Vries S, Frumkin H. Nature and health. Annu Rev Public Health 2014;35:21.1–21.22. Epub 2014 Jan 2.

Hayes A.R., C.F. Mancino and I.L. Pepper. 1990. Irrigation of Turfgrass with Secondary Sewage Effluent: I. Soil and Leachate Water Quality. Agron. Journal. 82:939-943.

Heckman, J.R. and D. Kluchinski. 1996. Waste management: chemical composition of municipal leaf waste and hand-collected urban leaf litter. J. of Environmental Quality. 25:355-362.

Heerwagen, J.H. and G.H. Orians. 2002. The ecological world of children. *In*: Kahn, P.H.J., and S.R. Kellert (eds.), Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations. MIT Press, Cambridge MA, pp. 29-64.

Hodges, A.W., J.J. Haydu, P.J. van Blokland, and A.P. Bell. 1994. Contributions of the Turfgrass Industry to Florida's Economy, 1991-1009: A Value-added Approach. Institute of Food and Agricultural Sciences, University of Florida, Gainesville, Florida. Pages 1-16.

Hyde, C.G. 1937. The beautification and irrigation of golden gate park with activated sludge effluent. Sewage Works Journal. 9:929-941.

Ignatieva, M., F. Eriksson, T. Eriksson, P. Berg, and M. Hedblom. 2017. The lawn as a social and cultural phenomenon in Sweden. Urban Forestry and Urban Greening. 21:213–223.

James, P., J.E. Hart, R.F. Banay, and F. Laden. 2016. Exposure to greenness and mortality in a nationwide prospective cohort study of women. Environmental health perspectives. 124:1344-1352.

Jenerette, G.D., S.L. Harlan, W.L. Stefanov, and C.A. Martin. 2011. Ecosystem services and urban heat riskscape moderation: water, green spaces, and social inequality in Phoenix, USA. Ecological Applications 21(7): 2637-2651.

Kahn Jr., P.H., and S.R. Kellert. 2002. Children and Nature: Psychological, Sociocultural, and Evolutionary Investigations. MIT Press, Cambridge MA.

Kane, S.P. and K.L. Wolfe. 2012. Economic Contribution of Turfgrass Production, Ornamental Horticulture, Landscape Services, and Related Industry in the Georgia Economy, 2010. Center for Agribusiness and Economic Development, The University of Georgia, Athens, Georgia. Pages 1-16.

Kelz, C., G.W. Evans, and K. Röderer. 2015. The restorative effects of redesigning the schoolyard: a multi-methodological, quasi-experimental study in rural Austrian middle schools. Environ. Behav. 47 (2), 119–139

Kelleher, S.R. 2020. Are golf courses essential during the COVID-19 crisis? It depends where you live. Forbes. Retrieved April 10, 2020. https://www.forbes.com/sites/suzannerowankelleher/2020/04/10/are-golf-courses-essential-during-covid-19-crisis-it-depends-where-you-live/#54f5522a1a24

Kowalewski, A.R., B.M. Schwartz, A.L. Grimshaw, J.N. McCrimmon and J.M. Layton. 2014. Mowing requirement and cost to maintain bermudagrass is influenced by cultivar selection and trinexapac-ethyl use. Applied Turfgrass Science. 11:1-9.

Kowalewski, A.R., R.N. Calhoun, A.D. Hathaway, and J.N. Rogers. 2010. Using cultural practices and leaf mulch to control weeds in established turfgrass. Applied Turfgrass Science. 7:1-10.

Kowalewski, A.R., T.W. Stock, B.W. McDonald, C.M. Mattox and B.L. Daviscourt. 2016. Developing and delivering a needs-based integrated pest management program for public school grounds employees. Natural Science Education. 45:1-14.

Krebs, C.C. 2020. Advisory memorandum on identification of essential critical infrastructure workers during COVID-19 response. United States Department of Homeland Security. Retrieved June 4, 2020. https://www.cisa.gov/sites/default/files/publications/Version_3.0_CISA_Guidance_on_Essential_Critical_Infrastructure_Workers_3.pdf

Krishnan, G., G.L. Horst, and P.J. Shea. 2000. Differential tolerance of cool- and warm-season grasses to TNT-contaminated soil. Int. J. Phytorem. 2:369–382. doi:10.1080/15226510008500045

Kuo, F.E. and W.C. Sullivan. 2001. Environment and crime in the inner city: does vegetation reduce crime? Environment and Behavior. 33:343-367.

Kuo, F.E., W.C. Sullivan, R.L. Coley, and L. Brunson. 1998. Fertile ground for community: Inner-city neighborhood common spaces. American Journal of Community Psychology, 26(6): 823-851

Laverne, R.J. and K. Winson-Geideman. 2003. The influence of trees and landscaping on rental rates at office buildings. J. Arboriculture. 29(5): 281-290.

Law, Q.D. and A.J. Patton. 2017. Biogeochemical cycling of carbon and nitrogen in cool-season turfgrass systems. Urban Forestry & Urban Greening 26:158-162.

Lin, C.H., R.N. Lerch, H.E. Garre, and M.F. George. 2004. Incorporating forage grasses in riparian buffers for bioremediation of atrazine, isoxaflutole and nitrate in Missouri. Agrofor. Syst. 63:91–99. doi:10.1023/B:AGFO.0000049437.70313.ef

Liu, G.C., J.S. Wilson, R. Qi, and J. Ying. 2007. Green neighborhoods, food retail, and childhood overweight: differences by population density. Am. J. Health. Promot. 21(4S):317-325.

Lusk, J., J. Anderson, D. Charlton, K. Coble, A. Davis, A. Dewey, J.H. Dorfman et al. 2020. Economic impacts of COVID-19 on food and agricultural markets. CAST Commentary. Retrieved June 29, 2020. https://www.cast-science.org/wp-content/uploads/2020/06/QTA2020-3-COVID-Impacts.pdf.

Mack, C.D., E.B. Hershman, R.B. Anderson, M.J. Coughlin, A.S. McNitt, R.R. Sendor, and R.W. Kent. 2019. Higher rates of lower extremity injury on synthetic turf compared with natural turf among National Football League athletes: epidemiologic confirmation of a biomechanical hypothesis. Amer. J. Sports Med. 47(1):189-196. https://doi.org/10.1177/0363546518808499.

Mancino, C.F. and I.L. Pepper. 1992. Irrigation of turfgrass with secondary sewage effluent: soil quality. Agron. Journal. 84:650-654.

Manandhar S., T. T. Suksaroj, and C. Rattanapan. 2019. The association between green space and the prevalence of overweight/obesity among primary school children. Int. J. Occup. Environ. Med. 10:1-10. doi: 10.15171/ijoem.2019.1425

Monteiro, J.A. 2017. Ecosystem services from turfgrass landscapes. Urban Forestry and Greening. 26:151-157. https://doi.org/10.1016/j.ufug.2017.04.001

Moore, P. 1981. The well-managed lawn. Nature 291. 14. https://doi-org.proxy.lib.utk.edu/10.1038/291014a0

Miyamoto, S. and A. Chacon. 2004. Soil salinity of urban turf areas irrigated with saline water: II. soil factors. Landscape and Urban Planning. 77:28-38.

Montgomery, J. A., C. A. Klimas, J. Arcus, C. DeKnock, K. Rico, Y. Rodriguez, K. Vollrath, E. Webb, and A. Williams. 2016. Soil quality assessment is a necessary first step for designing urban green infrastructure. J. Environ. Qual. 45(1):18-25.

National Golf Foundation (NGF). 2020. COVID-19 Update. Retrieved May 12, 2020. https://www.thengfq.com/covid-19/

National Golf Foundation (NGF). 2017. Estimating the charitable impact of golf. Retrieved June 8, 2020. https://www.ngf.org/report/charitable-impact-of-golf/

Nicholls, S. and J.L. Crompton. 2007. The impact of a golf course on residential property values. J. Sport Mgt. 21:555-570.

Parmet, W.E. and M.S. Sinha. 2020. Covid-19 – The law and limits of quarantine. N. Engl. J. Med. 382:e28. DOI: 10.1056/NEJMp2004211

Patton, A.J., B.M. Schwartz and K.E. Kenworthy. 2017. Zoysiagrass (*Zoysia* spp.) history, utilization, and improvement in the United States: a review. Crop Sci. 57:37-72.

Qian, Y.L. and R.F. Follett. 2002. Assessing soil carbon sequestration in turfgrass systems using long-term soil testing data. Agron. J. 94:930–935.

Ratnesar-Shumate, S., G. Williams, B. Green, M. Krause, B. Holland, S. Wood, J. Bohannon, J. Boydston, D. Freeburger, I. Hooper, K. Beck, J. Yeager, L.A. Altamura, J. Biryukov, J. Yolitz, M. Schuit, V. Wahl, M. Hevey, and P. Dabisch. 2020. Simulated sunlight rapidly inactivates SARS-CoV-2 on surfaces. *J. Infectious Diseases*. 222(2): 214–222. doi:10.1093/infdis/jiaa274.

Riper, C.V. and J. Geselbracht. 2020. Water reclamation and reuse. Water Environ. Research. 7:720-728.

Sadler, R.C., J. Pizarro, B. Turchan, S.P. Gasteyer, and E.F. McGarrell. 2017. Exploring the spatial-temporal relationships between a community greening program and neighborhood rates of crime. Applied Geography. 83:13-26.

Scheyer, J.M. and K.W. Hipple. 2005. Urban Soil Primer. United States Department of Agriculture, Natural Resources Conservation Service, National Soil Survey Center, Lincoln, Nebraska (http://soils.usda.gov/use).

Shahandeh, H. and L.R. Hossner. 2000. Plant screening for chromium phytoremediation. Int. J. Phytorem. 2:31–51. doi:10.1080/15226510008500029

Sharma, H.D. and A. De. 2007. Municipal solid waste landfill settlement: Postclosure perspectives. J. Geotechnical and Geoenvironmental Engineering. 133:619-629.

Shraddha M., T.T. Suksaroj, and C. Rattanapan. 2019. The Association between green space and the prevalence of overweight/obesity among primary school children. Int. J. Occup. Environ. Med. 10(1): 1–10. doi: 10.15171/ijoem.2019.1425

Sohrabi C, Z. Alsafi, N. O'Neil, M. Khan, A. Kerwan, A. Al-Jabir, C. Iosifidis, and R. Agha. 2020. World Health Organization declares a global emergency: A review of the 2019 novel coronavirus (COVID-19). International. J. Surgery. 76:71-76.

SRI International. 2012. The 2011 golf economy report. Retrieved June 8, 2020. http://wearegolf.org/wp-content/uploads/2019/01/2011-golf-econ-exec-sum-sri-final-12-17-12.pdf

State of Michigan. 2020. Coronavirus Executive Order 2020-42 FAQs. Official Website of Michigan.gov. Retrieved August 4, 2020 https://www.michigan.gov/coronavirus/0,9753,7-406-98178_98455-525278--,00.html

State of Oregon. 2020. Masks Required Statewide. Retrieved August 4, 2020. https://govstatus.egov.com/or-oha-face-coverings

Stenner, B.J., A.D. Mosewich, and J.D. Buckley. 2016. An exploratory investigation into the reasons why older people play golf. Qualitative Research in Sport, Exercise and Health. 8:257-272.

Stier, J. C., K. Steinke, E. H. Ervin, F. R. Higginson, and P. E. McMaugh. 2013. Turfgrass benefits and issues. In Stier, John C., Horgan, Brian P., and Bonos, Stacy A. (eds.) Turfgrass: Biology, Use, and Management. Madison, Wisconsin: American Society of Agronomy.

Tanner, R.A. and A.C. Gange. Effects of golf courses on local biodiversity. 2005. Landscape Urban Planning 71:137-146.

Thwaites, R.H., M.R. Ashmore, A.J. Morton, and R.J. Pakeman. 2006. The effects of tropospheric ozone on the species dynamics of calcareous grassland. Environ. Pollut. 144:500-509.

Thompson, G.L. and J. Kao-Kniffin, 2017. Applying biodiversity and ecosystem function theory to turfgrass management. Crop Sci. 57: S-238-S-248. doi:10.2135/cropsci2016.05.0433

Thompson, O.A., D.C. Wolf, J.D. Mattice, and G.J. Thoma. 2008. Influence of nitrogen addition and plant root parameters on phytoremediation of pyrene-contaminated soil. Water Air Soil Pollut. 189:37–47. doi:10.1007/s11270-007-9552-4.

Tordoff, G.M., A.J.M. Baker, and A.J. Willis. 2000. Current approaches to the revegetation and reclamation of metalliferous mine wastes. Chemosphere 41:219–228. doi:10.1016/S00456535(99)00414-2

Troy, A., A. Nunery, and J. M. Grove. 2016. The relationship between residential yard management and neighborhood crime: An analysis from Baltimore City and County. Landscape and Urban Planning 147:78-87.

van Klink, R., D.E. Bowler, K.B. Gongalsky, A.B. Swengel, A. Gentile, J.M. Chase. 2020. Meta-analysis reveals declines in terrestrial but increases in freshwater insect abundances. Science. 386:417-420.

Van Renterghem, T.V., J. Forssen, K. Attenborough, P. Jean, J. Defrance, M. Hornikx, and J. Kang. 2015. Using natural means to reduce surface transport noise during propagation outdoors. Applied Acoustics. 92:86-101. https://doi.org/10.1016/j.apacoust.2015.01.004

Venter Z., D. Barton, V. Gundersen, H. Figari, and M. Nowell. 2020. Urban nature in a time of crisis: recreational use of green space increases during the COVID-19 outbreak in Oslo, Norway. Environ. Res. Lett. doi: 10.1088/1748-9326/abb396

Wang, J., C. Monger, X. Wang, M. Serena, and B. Leinauer. 2016a. Carbon sequestration in response to grassland-shrubland-turfgrass conversions and a test for carbonate biomineralization in desert soils, New Mexico, USA. Soil Science Society of America Journal 80: 1591-1603.

Wang, Z., X. Zhao, J. Yang, and J. Song. 2016b. Cooling and energy saving potentials of shade trees and urban lawns in a desert city. Applied Energy 161: 437-444.

Wang, F., M. Qiao, Z. Lv, G. Guo, Y. Jia, Y. Su and Y. Zhu. 2014. Impact of reclaimed water irrigation on antibiotic resistance in public parks, Beijing, China. Environmental Pollution. 184:247-253.

Ward, J.S., J.S. Duncan, A. Jarden, and T. Stewart. 2016. Health Place 40:44-50. doi: 10.1016/j.healthplace.2016.04.015

Watkins, E., D.S. Gardner, J.C. Stier, D.J. Soldat, R.A. St. John, N.E. Christians, A.D. Hathaway, K.L. Diesburg, S.R. Poppe and R.E Gaussoin. 2014. Cultivar performance of low-input turfgrass species for the north central United States. Applied Turfgrass Science. 11:1-7

Wheeler, M.M., C. Neill, P.M. Groffman, M. Avolio, N. Bettez, J. Cavender-Bares, R.R. Chowdhury, J.M. Grove, S.J. Hall, J.B. Heffernan, S.E. Hobbie, K.L. Larson, J.L. Morse, K.C. Nelson, L.A. Ogden, J. O'Neil-Dunne, D.E. Pataki, and T.L.E. Trammell. 2017. Continental-scale homogenization of residential lawn plant communities. Landscape and Urban Planning. 165:54-63.

Wells, N.M. and K. Rollings. 2012. The natural environment in residential settings: influences on human health and function. *In*: The Oxford Handbook of Environmental and Conservation Psychology. Oxford University Press, Oxford, pp. 509–523.

World Health Organization (WHO). 2020. Coronavirus Disease (COVID-19). Dashboard. Retrieved August 4, 2020. https://covid19.who.int/?gclid=Cj0KCQjwnv71BRCOARIsAIkxW9HQzUwWD8F3oyzv0L_92a9hH9FqaamwdG5DnPp5SX2hKV5Xbf7pkekaAn1bEALw_wcB

World Health Organization (WHO). 2012. Health Indicators of sustainable cities. *In* Proceedings of the United Nations Conference on Sustainable Development, Rio de Janeiro, Brazil, 20–22 June 2012.