Ecotoxicology and Environmental Safety 156 (2018) 420–427

Contents lists available at ScienceDirect

Ecotoxicology and Environmental Safety

journal homepage: www.elsevier.com/locate/ecoenv

Chemical application strategies to protect water quality☆

Pamela J. Rice[a,*], Brian P. Horgan[b], Brian L. Barber[c], William C. Koskinen[a]

[a] US Department of Agriculture - Agricultural Research Service, St. Paul, MN 55108, USA
[b] University of Minnesota, Department of Horticultural Science, St. Paul, MN 55108, USA
[c] University of Minnesota, Department of Soil, Water and Climate, St. Paul, MN 55108, USA

ARTICLE INFO

Keywords:
Application setbacks
Fertilizer
Management practices
Pesticides
Runoff
Turfgrass

ABSTRACT

Management of turfgrass on golf courses and athletic fields often involves application of plant protection products to maintain or enhance turfgrass health and performance. However, the transport of fertilizer and pesticides with runoff to adjacent surface waters can enhance algal blooms, promote eutrophication and may have negative impacts on sensitive aquatic organisms and ecosystems. Thus, we evaluated the effectiveness of chemical application setbacks to reduce the off-site transport of chemicals with storm runoff. Experiments with water soluble tracer compounds confirmed an increase in application setback distance resulted in a significant increase in the volume of runoff measured before first off-site chemical detection, as well as a significant reduction in the total percentage of applied chemical transported with the storm runoff. For example, implementation of a 6.1 m application setback reduced the total percentage of an applied water soluble tracer by 43%, from 18.5% of applied to 10.5% of applied. Evaluation of chemographs revealed the efficacy of application setbacks could be observed with storms resulting in lesser (e.g. 100 L) and greater (e.g. > 300 L) quantities of runoff. Application setbacks offer turfgrass managers a mitigation approach that requires no additional resources or time inputs and may serve as an alternative practice when buffers are less appropriate for land management objectives or site conditions. Characterizing potential contamination of surface waters and developing strategies to safeguard water quality will help protect the environment and improve water resource security. This information is useful to grounds superintendents for designing chemical application strategies to maximize environmental stewardship. The data will also be useful to scientists and regulators working with chemical transport and risk models.

1. Introduction

Tended lawns are commonly found around buildings (residential, commericial, institutional and municipal), along roadsides, in cemetaries, and associated with recreational spaces such as parks, athletic fields and golf cources. More than 32,000 golf courses are located throughout the world with an estimated 17,000 golf courses in the United States (Saito, 2010; World Golf, 2017; World Golf Foundation, 2017). Maintained turfgrass represents on average 67% of an 18-hole golf course (GCSSA, 2007). Some of the most highly managed turfgrass is found on golf courses greens and fairways where irrigation can be more frequent and application rates of fertilizer and pesticides can exceed those found in agricultural settings and home environments (Barbash and Resek, 1996; Gianessi and Anderson, 1996; Smith and Bridges, 1996). Plant protection products offer benefits to the turfgrass systems in which they are applied. Conversely, their potential off-site transport into nearby surface waters incites concern for aquatic biota as excess nutrients may result in eutrophication and harmful algal blooms and pesticides are biologically active compounds designed to interfere with metabolic processes (Matsumura, 1985; U.S. Environmental Protection Agency, 1999; Cohen et al., 1999; Hoffman et al., 2000; Gilliom et al., 2006; Ansari et al., 2011). Therefore it is important to identify management practices that will reduce the off-site transport of plant protection products in order to lessen potential adverse impact to surrounding areas and ecosystems.

Plant protection products can be transported from their point of application to adjacent areas with overland flow. This has been documented with concentrations measured directly in storm runoff and in runoff catchments, as well as supported by detection of land-applied chemicals in surface waters throughout the world (Cohen et al., 1999; Hoffman et al., 2000; Soulsby et al., 2004; Rice et al., 2011; Gilliom et al., 2006; Nash et al., 2005; Xu et al., 2007; Bakri et al., 2008; Pärn

---

Abbreviations: DFBA, 2,6-difluorobenzoic acid; PFBA, pentafluorobenzoic acid; KBr, potassium bromide; TFMBA, *o*-(trifluoromethyl)benzoic acid

☆ Reference to specifice products does not imply endorsement by U.S. Department of Agriculture or the University of Minnesota to the exclusion of other suitable products.

* Correspondence to: U.S. Department of Agriculture–ARS, 1991 Upper Buford Circle, Borlaug Hall, Room 439, St. Paul, MN 55108, USA.
E-mail address: pamela.rice@ars.usda.gov (P.J. Rice).

https://doi.org/10.1016/j.ecoenv.2018.02.030
Received 22 October 2017; Received in revised form 1 February 2018; Accepted 7 February 2018

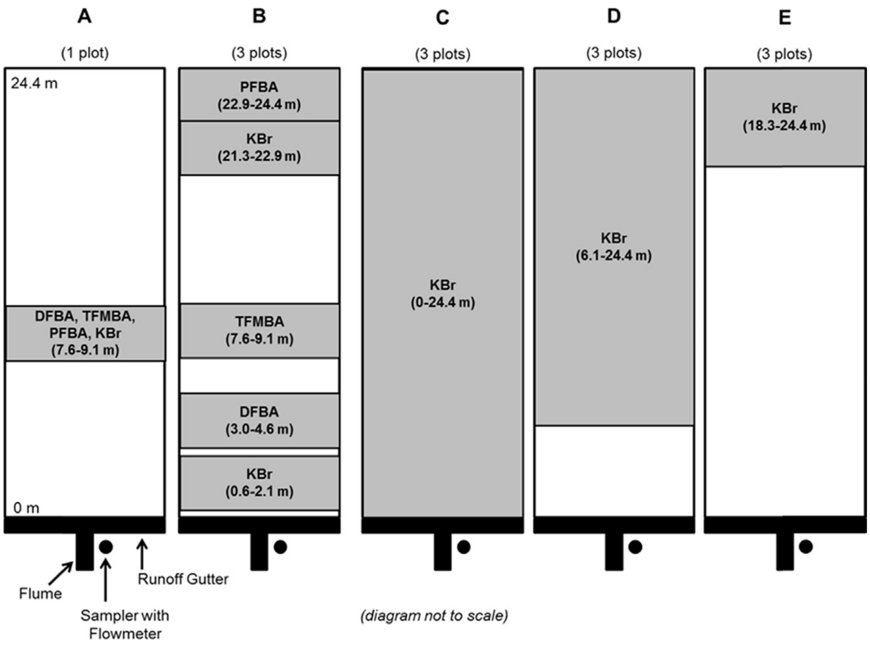

Fig. 1. Diagram of turfgrass plot experiments to evaluate the influence of application setback distances. The initial study (A and B) utilized multiple analytically-distinct tracer compounds to (A) compare the mobility of the four tracer compounds with runoff, and (B) evaluate use of these multiple tracer compounds to simultaneously evaluate application setback distances. Subsequent studies (C-E) evaluated the influence of application setback distances using a single tracer compound and one application setback distance each year during a three year study. Evaluation A was observed on a single plot. Experiments B-E were replicated on three plots. DFBA = 2,6-Difluorobenzoic acid; TFMBA = *o*-(Trifluoromethyl)benzoic acid; PFBA = Pentafluorobenzoic acid; KBr = potassium bromide.

et al., 2012; Fairbairn et al., 2016). Management practices have been shown to reduce runoff and quantity of nutrients and pesticides transported with runoff from agricultural crops (Hansen et al., 2001; Rice et al., 2007; Potter et al., 2015) and managed turfgrass (Cole et al., 1997; Rice et al., 2010b; Rice and Horgan, 2011). Vegetative filter strips or buffers, vegetative areas adjacent to surface waters designed to intercept stormwater runoff, are an example of a mitigation approach to reduce contaminant transport from developed property and land in production of agricultural crops (SULIS, 2017; Lerch et al., 2017; Franco and Matamoros, 2016; Carluer et al., 2017). In July 2015 the Minnesota Buffer Law was established requiring landowners in Minnesota, USA, to implement perennial vegetation buffers on public waters; up to 15.2 m (50 ft) along lakes, rivers and streams and 5.0 m (16.5 ft) along ditches (https://mn.gov/portal/natural-resources/buffer-law). Flexibility for alternative practices may be considered when buffers are less appropriate for land management objectives or site conditions; however, the alternative practice must provide water quality benefits comparable to that provided by a buffer (https://mn.gov/portal/natural-resources/buffer-law/practices). In suburban/urban environments open land is less prevelant and the installation of mixed-vegetation perennial-buffers may be less asethetically desired. In addition, research has shown that densely uniform manicured lawns have reduced frequency and total volume of runoff and less nutrient loss with runoff than low maintenance lawns and residential forested landscapes (Spence et al., 2012). For this reason our goal was to investigate application setbacks as an alternative practice to mitigate the off-site transport of applied chemicals with runoff from turf managed as a golf course fairway.

Golf courses can be found adjacent to natural surface waters (e.g. rivers, lakes, oceans) as well as contain surface waters within the course. In fact golf course designs often include water features in the form of ponds or creeks surrounded by fairways, turfgrass maintained between 1.27 cm and 3.18 cm height-of-cut depending on the grass species (Kains, 2017; Kelly, 2017). These surface waters act as a hazard to increase the challenge of play as well as improve golf course aesthetics, enhance drainage and water storage for irrigation, and provide habitat for wildlife. For this research we evaluated creeping bentgrass, the most commonly used turfgrass for fairways, putting greens and tees in cool and humid climates (Riggs, 2008). Experiments were performed with highly water soluble tracer compounds that would represent transport of inorganic fertilizer or a worst-case scenario for highly water soluble and minimally adsorbed pesticides. If proven effective, application setback distances could offer turfgrass managers an alternative practice to enhance environmental stewardship through mitigation of nonpoint source contamination of surrounding surface waters.

2. Materials and methods

2.1. Turf plots equipped with runoff collection systems

Runoff experiments were conducted on plots (24.4 m length x 6.1 m width, graded to a 5 ± 1% slope running east to west) sodded with *Agrostis palustris* Huds. (L-93 creeping bentgrass) at the University of Minnesota Turfgrass Research and Outreach Center (Saint Paul, MN, USA). The bentgrass was managed as a golf course fairway with 1.27 cm height of cut (3 times weekly), top-dressed with 1.6 mm depth of sand (weekly), periodically irrigated to prevent drought stress, and aerated (11 ± 4 d prior to the runoff events) with hollow tines measuring 11.43 cm depth x 0.95 cm internal diameter, spaced 5 cm × 5 cm (Ryan Greensaire II Aerator, Ryan, Barrington, IL, USA). The soil below the turfgrass was characterizes as Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed superactive, mesic Typic Hapludolls; 55% silt, 29% sand, 16% clay) with 3% organic carbon and bulk density of 1.37 ± 0.24 g cm^{-3} for 0–7.62 cm depth.

Runoff collection systems were constructed at the down-slope (western) edge of each plot, modified from the design of Cole et al. (1997) (Fig. 1). Stainless-steel flashing directed runoff from the turf into 6.1-m gutters (horizontally-split 15.2-cm schedule 40 polyvinyl chloride (PVC) pipe that were joined in the center with a PVC-T (15.2 cm × 15.2 cm × 15.2 cm)). Water flowed from the gutter into a stainless steel large 60° V trapezoidal flume (Plasti-Fab) equipped with a bubble tube port and two sample collection ports. The gutter system and trapezoidal flume were supported in sand-filled trenches to maintain appropriate conditions for accurate measurement of runoff volume and flow rates. Gutter covers and flume shields prevented dilution of runoff with precipitation. Runoff water samples were collected using an automated sampler (Teledyne ISCO model 6700) equipped with a flow meter (Teledyne ISCO model 730) that recorded water level in the flume, reported flow rates, calculated total runoff volume and triggered collected of 24 time-paced (5 min) samples for each plot. Samples were stored at 4 °C until analysis.