Artificial Turf Football Fields: Environmental and Mutagenicity Assessment

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Abstract The public has recently raised concerns regarding potential human health and environmental risks associated with tire crumb constituents in the artificial turf of football fields. The aim of the present study was to develop an environmental analysis drawing a comparison between artificial turf football fields and urban areas relative to concentrations of particles (PM10 and PM2.5) and related polycyclic aromatic hydrocarbons (PAHs), aromatic hydrocarbons (BTXs), and mutagenicity of organic extracts from PM10 and PM2.5. No significant differences were found between PM10 concentrations at an urban site and on a turf football field, both during warm and in cold seasons, either with or without on-field activity. PM2.5 concentrations were significantly greater at the urban site in the cold season as was the ratio of PM2.5 to PM10. BTXs were significantly greater at urban sites than on turf football fields on both on warm and cold days. The ratio of toluene to benzene (T/B ratio) was always comparable with that of normal urban conditions. The concentration of PAHs on the monitored football fields was comparable with urban levels during the two different sampling periods, and the contribution of PAHs released from the granular material was negligible. PM10 organic extract mutagenicity for artificial turf football fields was greater, whereas PM2.5 organic extract mutagenicity was lower, compared with the urban site studied. However, both organic extract mutagenicity values were comparable with the organic extract mutagenicity reported in the literature for urban sites. On the basis of environmental monitoring, artificial turf football fields present no more exposure risks than the rest of the city.

Recycled tire material, or "tire crumb," is used as a component of many recreational fields, including artificial turf fields. These crumbs constitute as much as 90 % (by weight) of the fields. The tire crumbs are approximately the size of grains of coarse sand, and they are made by shredding and grinding used tires. Tire crumb materials are spread two to three inches thick over the field surface and packed between ribbons of green plastic used to simulate green grass (Environment and Human Health, Inc. [EHHI] 2007). Tire rubber is composed of 40–60 % rubber polymer and reinforcing agents, such as carbon black (20–35 %), aromatic extender oils (15–20 %), vulcanisation additives (4 %, i.e., zinc oxide, benzothiazole, and derivatives), antioxidants (1 %), and processing aids (<1 %, i.e., plasticisers and softeners) (Wik and Dave 2009). The use of tire crumbs in applications such as football fields provides several benefits, including decrease of sports injuries. Non-playground applications include use tire crumbs as an asphalt additive in road building and as an aggregate in concrete. Tire crumb contribute to the strength of concrete, and the combined product is reportedly lighter in weight than typical concrete (Pierce and Blackwell 2003).

The public recently has raised concerns regarding potential human health and environmental risks associated with the presence of and potential exposures to tire crumb constituents in recreational fields, especially regarding children's exposures (United States Environmental

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Protection Agency [USEPA] 2009). Adults, and especially children, playing on tire crumb could potentially be exposed to these tire crumb constituents by inhalation of dust, skin contact with the material or surface water runoff, ingestion of the product directly, or ingestion of surface water runoff through the product. Public health analysis of the health risks from human exposure to rubber tire crumbs has not been adequately addressed to date (Anderson et al. 2006).

Concerns have been expressed that toxic chemicals derived from tire rubber could be transferred to the environment and to organisms having direct contact with these products. Chemical additives, such as zinc and polycyclic aromatic hydrocarbons (PAHs), have been widely detected in leachate from tire rubber (Stephensen et al. 2003; Wik and Dave 2005; Kanematsu et al. 2009; Menichini et al. 2011). Zhang et al. (2008) reported that the levels of PAHs and Zn in tire crumbs used as infill for artificial turf were greater than health-based soil standards and that lead in tire crumbs was highly bioaccessible in synthetic gastric fluid at relatively low levels (Zhang et al. 2008). It is improbable that the metals could be present at a risk level in the air on artificial turf, especially in the fine particles (Menichini et al. 2011).

To further examine the known risks to humans from exposure to the playground product, Anderson et al. (2006) turned to the traditional published scientific literature. One study, performed by investigators working in Alberta (Birkholz et al. 2003), examined the human and ecosystem hazards presented by tire crumbs using *in vitro* mutagenicity assays. The associated hazard analysis suggested that the risk associated with playground use was low. Toxicity to all of the aquatic organisms tested was observed in the fresh aqueous extract, but the activity disappeared with aging of the tire crumb for 3 months in place on the playground. The investigators concluded that the use of tire crumb on playgrounds results in minimal hazard to children and the environment, assuming that the product is used as intended as well as exclusive outdoor use and the presence of no solvents other than water.

Regarding the central question of potential harm to children, the published literature contains some information about the product, including in vitro toxicity models (Gualtieri et al. 2005; Wik and Dave 2006; Mantecca et al. 2007; Gomes et al. 2010). Most previous work has focused on toxic chemicals in leachate from tire rubber material. Wik and Dave (2009) reviewed the ecotoxicological effects of tire rubber leachate thoroughly and indicated the potential risks to aquatic organisms in water and sediment (Wik and Dave 2009). The report went on to indicate that the health aspects associated with the inhalation of rubber particles are largely unknown. Limited work has been performed on the characterisation of volatile and semivolatile organic compounds

out-gassing from commercial tire crumb on artificial turf fields (USEPA 2009; Li et al. 2010; van Rooij and Jongeneelen 2010). This is despite the fact that if tire crumb is used as infill for artificial turf, the inhalation zone over these installations could be a major source of human exposure. Traditional published resources and networks of environmental health experts could not establish the safety of tire crumb products in use with children or adults present (Anderson et al. 2006). The possible danger for children or adults is from direct contact with chemical compounds contained in the crumbs. Direct contact could happen by ingestion or as a result of contact. A qualitative assessment of these risks produced the following conclusions: Ingestion on the ground is unlikely, and the gastric juices of the digestive system are not powerful enough to extract the toxic products from the crumb. Dermatological contact generally presents a low risk: A solvent that is more effective than water would be needed to extract toxic compounds in quantity, and an adequate (nonpolar) carrier would be necessary to penetrate the skin and cause significant absorption. Inhalation is considered negligible because the crumbs do not contain volatile chemical compounds under pressure; however, as the tires wear, even the use of an artificial field could generate fine particles and related compounds (Birkholz et al. 2003; Laboratoire de Recherches et de Contrôle du Caoutchouc et des Plastiques [LRCCP] 2006).

An environmental analysis is needed for quantitative determination of contamination levels due to the presence of tire crumbs in artificial turf fields. Determination of whether an artificial turf field can produce an exposure level greater than that of normal exposure levels to pollutants in urban areas is important. The aim of the present study was to develop an environmental analysis drawing a comparison between artificial turf football fields and urban areas in relation to the following: (1) the concentration of particles (PM10 and PM2.5); (2) the concentration of related PAHs; (3) the concentration of aromatic hydrocarbons (benzene, toluene, and xylene [BTX]); and (4) the mutagenicity of the organic extracts of the PM and PM2.5. These analyses were conducted both in the presence and in the absence of the use of the turf fields and, to understand how natural weathering conditions influence the levels of chemicals released from turf fields, during two different seasons.

Materials and Methods

Sampling Sites

The sampling was performed in Torino, an industrial northwestern Italian city, on six different football fields (five were artificial turf) and at two atmospheric

meteorological–chemical control stations located in the urban centre (1A and 1B [both Piedmont ARPA]). The atmospheric meteorological–chemical control stations belong to the Environmental Protection Regional Agency (Piedmont ARPA). The chemical analyses were decided on and conducted by the agency to perform analyses as part of the regular national monitoring programme for air quality (Air Quality Directive 2008/50/CE). The characteristics of the sampling sites are listed in Table 1. Two different courses of sampling were performed to verify the influence of both meteorological and seasonal conditions and the presence of play: in June 2006 (from June 12 to 26) without playing activity for at least 2 weeks and in November 2006 (from November 6 to 15) during the course of sporting matches.

PM Analysis

PM10 and PM2.5 were sampled on glass microfibre filters (type A/E, $8'' \times 10''$; Gelman Sciences, MI) with Sierra Andersen High Volume Samplers 1200/VFC (Andersen Samplers, Atlanta, GA) using a flow rate of approximately 1160 L/min. Sampling duration was controlled by a timer accurate to ± 15 min during a 24-h sampling period. The exact flow was calculated daily and corrected for variation in atmospheric pressure and actual differential pressure across the filter.

The filtres were preconditioned and postconditioned by moving them to a dry and dark environment for 48 h, and they were weighed in a room with controlled temperature and humidity. Procedures were conducted according to the European Committee for Standardization (CEN 1998). The PM10 and PM2.5 concentrations, C ($\mu g/m^3$), in the air volume sampled, V (L), were calculated as follows:

$$C = [(W2 - W1) - (B2 - B1)] \times 10^3/V,$$

where W1 is the mean of three tare weights of the same filtre before sampling (mg); W2 is the mean of three postsampling weights of the same sample-containing filtre (mg); B1 is the mean tare weight of the blank filtres (mg); B2 is the mean postsampling weight of blank filtres (mg); and V is the volume as sampled at the nominal flow rate. At all football-field sampling sites, the measurements were performed at the top of the penalty area, whereas for urban sampling sites, the measurements were performed at the atmospheric meteorological–control stations, one for PM10 (station 1A) and the other for PM2.5 (station 1B).

Aromatic Hydrocarbon Analysis

Measurements of benzene, toluene, and BTX levels were performed at all sites using a sampling line (airflow = 1 L/min) consisting of a membrane pump (KNF Neuberger, Germany, catalogue no. N73 KN 18), a gas meter (ZB1, Zambelli, Bareggio (MI), Italy), and a granular activated carbon (GAC) cartridge (coconut shell charcoal-adsorbent sample tubes, catalogue no. 226-01; SKC, Inc., Pensylvania). As reported in the SKC certificate of quality, these cartridges are calibrated at 25 °C. The factors of temperature and humidity are not significant except under the most extreme temperature conditions or >90 % relative humidity, conditions that did not occur at these sites during

Table 1 Characteristics of the sampling sites

Football field	Age (y)	Material	Dimensions (m)	First sampling	Second sampling	Site[b]	Emission type[c]
P1	3	Black UT[a]	45×90	12 June	6 November	Background	Residential/industrial
P2	3	Clay	45×90	13 June	7 November	Background	Residential/industrial
Carrara	1.5	Black UT[a]	40×65	14 June	8 November	Traffic	Residential/industrial
Rivermosso	3	Black UT[a]	40×65	15 June	9 November	Traffic	Residential/industrial
Passo Buole	3	Thermoplastic	45×90	21 June	14 November	Background	Residential/industrial
Barracuda	1.5	Black UT[a]	40×65	26 June	15 November	Traffic	Residential/industrial

Name of urban atmospheric meteorological-chemical control stations		First sampling	Second sampling
1A	Six-m high; in central limited traffic zone; emissions type = residential/commercial	12–26 June	6–15 November
1B	Two-m height; "sandwiched" between two busy streets and bordered with central limited traffic zone; emissions type = residential/commercial	12–26 June	6–15 November

[a] Used tires

[b] Site in relation to the motor vehicle traffic in the surrounding area (background/traffic)

[c] Emission type (residential/commercial/industrial)

this period. Cold temperatures do not interfere with the collection of chemical substances onto solid sorbents (SKC). At all football-field sampling sites, the measurements were taken at approximately 2-m height from street level and approximately at the top of the penalty area. For the urban sampling sites, measurements were taken at the atmospheric meteorological–chemical stations.

Air monitor samples were analysed using a Carlo Erba (Arese (MI), Italy) 5300 Mega Series gas chromatograph (GC) equipped with a flame ionisation detector (FID) and capillary column (DB-624, 30 m × 0.318 mm ID, film thickness 1.8 μm). Each sample was eluted using 3 mL ultrapure carbon disulphide (CS_2, 99.9 % low benzene content; Aldrich catalogue no. 34.227-0). A calibration curve was prepared from known concentrations of benzene, toluene, and BTX. The GC temperature program was as follows: 45 °C for 4 min, ramping up at 10 °C/min from 45 to 145 °C, then 145 °C for 2 min.

Sampling rates for the SKC passive sampler 530-11 were supplied by the manufacturer: benzene = 10.26 mL/min, toluene 9.05 = mL/min, m-xylene = 8.18 mL/min, o-xylene = 8.18 mL/min, p-xylene = 8.2 mL/min. The detection limit of 0.2 μg/sampler was calculated for the three aromatics with a signal-to-noise ratio ranging from 5 to 1. The accuracy of the analysis was determined by repeating the analysis of a sample 20 times. The mean of the 20 injections into GC/FID recorded benzene as 9.4 μg/m^{-3} (SD = 0.5) with a coefficient of variation of 4.3 %. Recovery (95 %) was determined using previously described techniques (Bono 2003). When the signal-to-noise ratio ranged from 5 to 1, there was no apparent benzene contamination of CS_2 bottles.

PAH Analysis

The following PAHs determined in this study were considered pollutants of priority interest and are categorised by the International Agency for Research on Cancer (IARC) as carcinogenic (group 1), probably carcinogenic (group 2A), and possibly carbinogenic (group 2B) to humans: benzo[a]pyrene (group 1), benzo[a]anthracene (group 2A), benzo[b]fluoranthene (group 2B), benzo[k]fluoranthene (group 2B), dibenzo[a,h]anthracene (group 2A), and indeno[1,2,3-c,d]pyrene (group 2B). Other PAHs were as follows: fluoranthene, pyrene, chrysene, benzo[ghi]perylene, phenanthrene, and anthracene. These PAHs were representative of total PAHs although the health effects of individual PAHs are not exactly similar (Agency for Toxic Substances and Disease Registry [ATSDR] 1995; Torben 1996). Benzo[a]pyrene is one of the PAHs that showed carcinogenic properties in animals, including humans (group 1 IARC) (Straif et al. 2005), and this compound is an excellent indicator of PAH exposure because it

correlates well with the other major carcinogenic PAHs (Feilberg et al. 2002). PAHs are products of incomplete combustion, are widespread in the environment, and may contribute to human cancer. However, the association between PAH exposure and lung cancer is considered unproven (Nielsen et al. 1996; Farmer et al. 2003). Determination of PAHs was performed on each PM10 and PM2.5 half filtre. The filtres were cut into small pieces and placed in a sterile 50-mL polypropylene tube with 15 mL toluene. The tubes were placed in an ultrasonic water bath for 15 min, followed by 1 min of vortexing. This procedure was repeated three times. Toluene extracts were evaporated to 2 mL with a rotary evaporator, then evaporated to 150 μL under a stream of nitrogen. The analytical method consisted of HRGC/LRMS using the method UT2.M128 R01 2002 (Pereira et al. 2001; Gilli et al. 2007a).

Mutagenicity Analysis

The PM_{10} and PM2.5 half-filtres were cut into small pieces with stainless steel scissors (approximately 0.5 × 0.5 cm) and extracted with acetone using a Soxhlet apparatus for at least 85 cycles. Acetone was able to extract moderately and highly polar classes of compounds. The polar fraction consistently contributed the highest percentage of mutagenicity, whereas the neutral nonpolar fraction contributed the least (Claxton et al. 2004). Solutions of mixtures of compounds were evaporated using a rotary evaporator and redissolved in dimethyl sulphoxide (DMSO) to obtain a concentration of 0.2 m^3/μL. The mutagenic activity of the PM10 extracts was determined using the *Salmonella* microsome assay (Ames test) according to the standard plate method of Maron and Ames (1983). Each sample was evaluated with and without metabolic activation (10 % S9 mix) using the TA98 *S. typhimurium* strain. The TA98 tester strain was checked routinely to confirm genotypes for optimal response to known mutagens as follows: 2-nitrofluorene (2-NF) at 1 μg/plate, was used as a positive control for TA98 without S9, and 2-aminofluorene (2-AF) at 2 μg/plate was used to assess microsomal fraction efficiency. Spontaneous reversion of the tester strains to histidine independence was measured in each Ames test and was expressed as the number of spontaneous revertants per plate.

Extracts containing the equivalent of 4, 8, or 16 m^3 (20, 40, or 80 μL of the DMSO 0.2 m^3/μL suspension) of sampled air were plated on histidine-free agar plates. The appropriate solvent controls were also included in each test to check sample preparation interferences. The series of concentrations of PM10 organic extracts was tested to generate a concentration-response curve. The slope of the concentration-response curve (revertants/m^3) was calculated by least-squares linear regression from the first linear

portion of the concentration-response curve. The regression coefficients obtained ranged from 0.67 to 0.99 (mean 0.89 ± 0.11 for TA98 and 0.87 ± 0.14 for TA98 + S9). All experiments were performed in triplicate with at least three concentrations. The results were expressed as net revertants (rev/m^3) by subtracting the spontaneous revertants and calculating according to the concentration-response curve (Buschini et al. 2001; Cassoni et al. 2004; Claxton et al. 2004).

Statistical Analysis

Statistical analyses were performed using SPSS Package, version 14.0, for Windows (SPSS, Chicago, IL). Means were compared using Student t test, and Spearman rank correlation coefficient (rS) was used to assess relationships between variables. The mean difference and correlation were considered significant at $p < 0.05$.

Results and Discussion

PM Concentrations

A total of 24 PM10 and 24 PM2.5 filters were analysed during the two sampling periods. The temperatures registered during the sampling periods in June were between 16 and 34 °C. During the November sampling period, the temperature ranged between 0 and 18 °C. Figures 1 and 2 show PM10 and PM2.5 concentrations, respectively, at the sampling sites during the two sampling periods. During the first sampling period in June, the mean PM10 concentrations were 59 ± 13 μg/m^3 and 54 ± 15 μg/m^3 at the urban site and on the turf football fields, respectively. The mean PM2.5 concentrations were 21 ± 3 μg/m^3 and 20 ± 4 μg/m^3 at the urban site and on the turf football fields, respectively. During the second sampling period in November, the mean PM10 concentrations were 110 ± 18 μg/m^3 and 103 ± 17 μg/m^3 at the urban site and on the turf football fields, respectively. The mean PM2.5 concentrations were 83 ± 13 μg/m^3 and 54 ± 7 μg/m^3 at the urban site and on the turf football fields, respectively.

No significant differences were found between PM10 concentrations at the urban site and on the turf football fields both on warm days and on cold days, either with or without playing. Neither the football-field traffic nor background sites influenced PM10 concentrations, except for the Rivermosso (R) football field, particularly in winter. This field was characterised by traffic and industrial emissions in the surrounding area. PM2.5 concentrations were significantly greater at the urban site on cold days ($p < 0.01$), whereas on warm days there was no difference ($p = 0.31$). Neither background nor traffic at the football-field sites influenced PM2.5 concentrations. Significant differences were found between PM10 and PM2.5 concentrations in June and November ($p < 0.01$).

The concentration ratios of PM2.5 to PM10 in November were 0.65 to 0.93 (mean 0.76 ± 0.10) at urban sites and 0.47 to 0.58 (mean 0.53 ± 0.04) on football turf fields. The difference was significant ($p < 0.01$). In June, the ratios were 0.27 to 0.43 (mean 0.37 ± 0.06) at urban sites and 0.29 to 0.49 (mean 0.39 ± 0.07) on turf football fields, respectively; this difference was not significant.

Fig. 1 PM10 concentrations at the sampling sites during the two sampling periods: 12 to 26 June (grey bars and striped bars) and 6 to 15 November (black bars and dotted bars). R artificial turf at Rivermosso, C artificial turf at Carrara, P1 artificial turf at Pellerina, P2 football field clay, B artificial turf at Barracuda, S artificial turf at Passo Buole
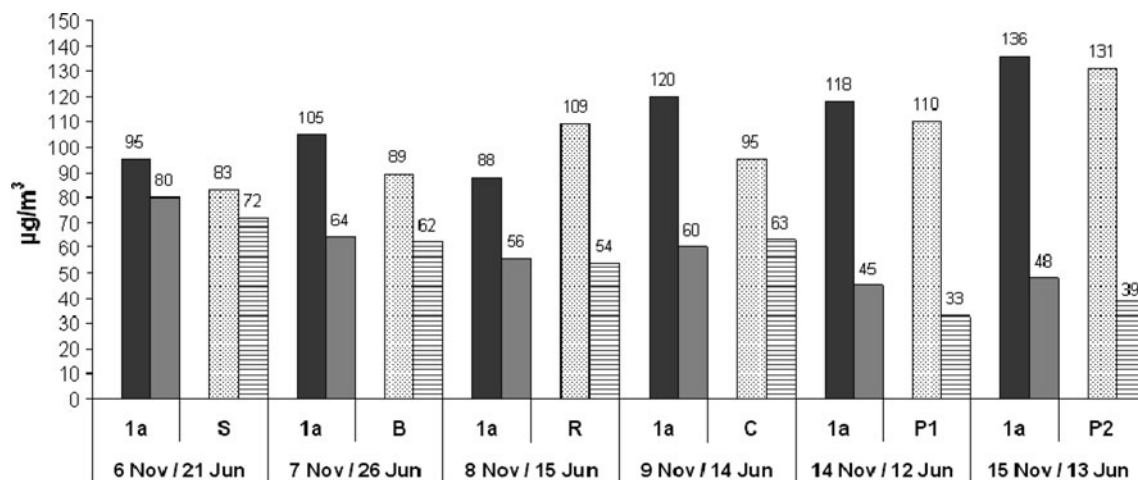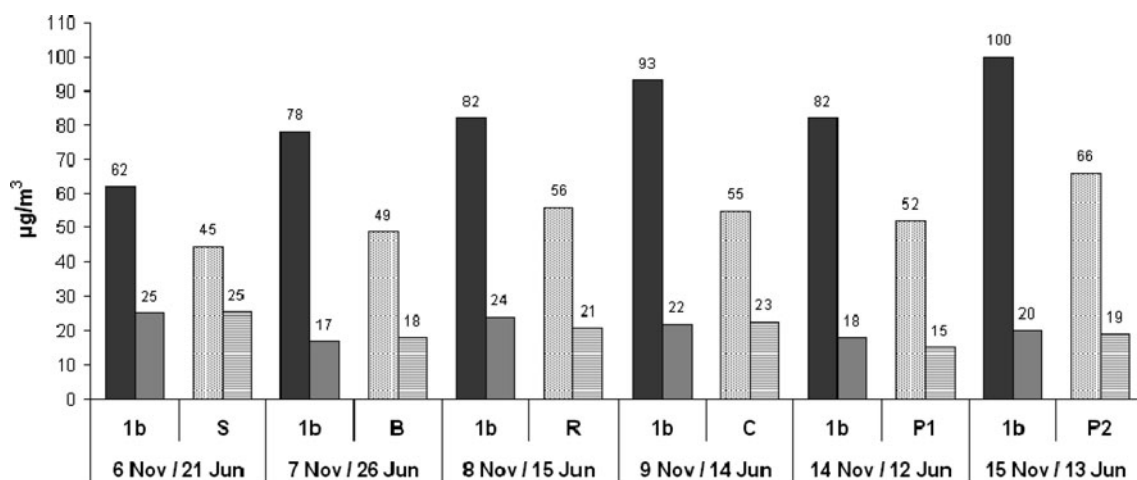
Fig. 2 PM2.5 concentrations at the sampling sites during the two sampling periods: 12 to 26 June (*grey bars* and *striped bars*) and 6 to 15 November (*black bars* and *dotted bars*). *R* artificial turf at Rivermosso, *C* artificial turf at Carrara, *P1* artificial turf at Pellerina, *P2* football field clay, *B* artificial turf at Barracuda, *S* artificial turf at Passo Buole

BTX Concentrations

A total of 24 GAC cartridges were analysed during the two sampling periods for the evaluation of BTX concentrations. In Table 2, BTX concentrations at the sampling sites during the June and November sampling periods are listed together with the means and SDs. Significant differences were found between BTX concentrations at the urban site and on the turf football fields both on warm days and on cold days. Mean BTX values were greater at urban sites than on the turf football fields ($p < 0.05$). Significant differences were also found between BTX concentrations in June and in November; the mean BTX values were greater in November ($p < 0.01$). Table 2 also lists ratios between benzene and toluene during the two sampling periods. The difference between the two sampling sites was significant.

Table 2 Benzene, toluene, and xylene plus T/B ratio at the sampling sites during the first and second samplings

	Urban control site (1A)				Football fields				
	Benzene	Toluene	X	T/B		Benzene	Toluene	X	T/B
12–26 June									
12 June	2.7	10.4	5.5	3.9	P1	1.8	10.2	20.9	5.7
13 June	3.0	11.5	5.8	4.0	P2	1.4	5.1	7.4	3.6
14 June	3.0	12.5	6.0	4.2	C	1.3	5.6	7.9	4.3
15 June	3.0	12.9	6.4	4.2	R	1.4	4.2	7.2	3.1
21 June	3.1	15.3	5.9	5.1	S	3.0	6.9	8.3	2.3
26 June	2.7	13.0	6.0	4.2	B	2.2	5.3	8.8	2.4
Mean ± SD	2.9 ± 0.1	12.5 ± 1.6	5.9 ± 0.4	4.3 ± 0.5	Mean ± SD artificial fields	1.9 ± 1.6	6.2 ± 2.1	10.1 ± 5.2	3.5 ± 1.2
6–15 November									
6 November	8.8	41.8	34.4	4.7	P1	6.0	18.9	25.7	3.1
7 November	7.4	38.4	25.8	5.2	P2	5.8	23.1	34.7	4.0
8 November	5.6	28.2	16.5	5.0	C	4.7	15.4	26.0	3.3
9 November	6.2	32.6	22.8	5.2	R	5.7	31.2	33.7	5.5
14 November	6.4	33.0	21.6	5.1	S	4.9	20.3	31.1	4.2
15 November	5.5	24.0	13.7	4.3	B	3.4	13.6	20.3	4.0
Mean ± SD	6.7 ± 1.3	33.0 ± 6.5	22.5 ± 7.3	4.9 ± 0.4	Mean ± SD artificial fields	5.1 ± 0.9	20.4 ± 6.3	28.5 ± 5.5	4.0 ± 0.8

X sum of m-xylene, o-xylene, and p-xylene concentrations ($\mu g/m^3$); *R* artificial turf at Rivermosso; *C* artificial turf at Carrara; *P1* artificial turf at Pellerina; *P2* football field clay; *B* artificial turf at Barracuda; *S* artificial turf at Passo Buole

Table 3 PAHs from PM10 and PM2.5 extraction at the sampling sites during the first and second samplings

PAH (ng/m³)		B[a]p	B[a]a	B[b]f + B[k]f	Db[ah]a	I[cd]p	Fluoranthene	Pyrene	Chrysene	B[ghi]pe	Phenanthrene	Anthracene
12–26 June												
12 June												
1a	PM10	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
1b	PM2.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
12 June	PM10	<LOD	<LOD	0.17	<LOD	<LOD	<LOD	<LOD	0.10	0.12	<LOD	<LOD
P1	PM2.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.10	<LOD	<LOD
13 June	PM10	<LOD	<LOD	0.15	<LOD	<LOD	<LOD	<LOD	<LOD	0.10	<LOD	<LOD
P2	PM2.5	<LOD	<LOD	0.13	<LOD	<LOD	<LOD	<LOD	<LOD	0.09	<LOD	<LOD
14 June	PM10	<LOD	<LOD	0.12	<LOD	<LOD	<LOD	<LOD	<LOD	0.09	<LOD	<LOD
C	PM2.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	< LOD	<LOD	<LOD	<LOD	<LOD
15 June	PM10	<LOD	<LOD	0.12	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
R	PM2.5	<LOD	<LOD	0.10	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
21 June	PM10	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	0.10	<LOD	<LOD	<LOD
S	PM2.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
26 June	PM10	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
B	PM2.5	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD	<LOD
6–15 November												
15 November												
1a	PM10	0.78	0.62	1.98	<LOD	0.70	0.34	0.48	0.62	0.78	<LOD	<LOD
1b	PM2.5	0.70	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
6 November	PM10	0.77	0.76	1.81	<LOD	0.50	0.57	0.69	1.00	0.65	0.17	<LOD
P1	PM2.5	0.70	0.57	1.61	<LOD	0.49	0.43	0.55	0.77	0.64	0.14	<LOD
7 November	PM10	0.34	0.44	1.06	<LOD	0.26	0.25	0.32	0.57	0.29	0.10	<LOD
P2	PM2.5	0.29	0.26	0.78	<LOD	0.23	0.15	0.19	0.31	0.27	<LOD	<LOD
8 November	PM10	1.19	1.20	2.53	0.12	0.69	0.45	0.62	1.53	0.87	0.12	<LOD
C	PM2.5	1.09	1.04	2.37	0.11	0.64	0.35	0.44	1.33	0.81	0.11	<LOD
9 November	PM10	1.75	2.13	3.98	0.19	1.03	0.56	0.71	2.24	1.22	0.15	<LOD
R	PM2.5	1.64	1.79	4.00	0.18	0.98	0.40	0.54	2.11	1.16	0.14	<LOD
14 November	PM10	1.49	1.53	3.18	0.25	1.01	0.94	1.32	1.98	1.31	0.24	<LOD
S	PM2.5	1.04	1.1	2.23	0.14	0.67	0.54	0.71	1.37	0.88	0.16	<LOD
15 November	PM10	0.82	0.95	2.08	<LOD	0.56	0.55	0.79	1.31	0.71	0.17	<LOD
B	PM2.5	0.72	0.62	1.70	<LOD	0.49	0.31	0.39	0.82	0.67	0.12	<LOD

R: artificial turf at Rivermosso; C: artificial turf at Carrara; P1: artificial turf at Pellerina; P2: football field clay; B: artificial turf at Barracuda; S: artificial turf at Passo Buole); B[a]p: benzo[a]pyrene; B[a]a: benzo[a]anthracene; B[b]f: benzo[b]fluoranthene; B[k]f: benzo[k]fluoranthene; Db[ah]a: dibenzo[a,h]anthracene; I[cd]p: indenol[1,2,3-c,d]pyrene; b[ghi]pe: benzol-g,h,i]perylene; LOD: 0.09 ng/m³; na: not available

The mean ratios were greater at urban sites than they were on the turf football fields (paired Student t test, p = 0.04).

PAH Concentrations

A total of 12 PAHs were analysed from both PM10 and PM2.5 extracts at each football field and at urban sites during the two sampling periods. In Table 3, PAH concentrations at the sampling sites during the June and November periods are listed. During the first sampling period in June (summer season), concentrations of PAHs, when present, were low. Among the PAHs analysed, benzo[a]pyrene is the only regulated compound and was never present. The only PAHs with values greater than the limit of detection (LOD), although low in concentration,

included benzo[b]fluoranthene + benzo[k]fluoranthene, which was present at four football fields (including the clay field) at least in the PM10 fraction; benzo[ghi]perylene, which was present on three football fields (including the clay field); and chrysene, which was present at two football fields but only in the PM10 fraction.

During the second sampling period in November (winter season), PAH concentrations were greater than during the summer period. Benzo[a]pyrene was always present on the football fields, with a mean value of 1.06 ± 0.51 ng/m^3, a concentration comparable with the concentrations reported as the annual average according to the current regulation level (1 ng/m^3). Except for anthracene, the other PAHs were often present on every football field and at the urban site; benzo[b]fluoranthene + benzo[k]fluoranthene, chrysene, and

Table 4 Mutagenicity of PM10 and PM2.5 organic extracts

	TA 98 revertants/m^3	TA 98 +S9 revertants/m^3	TA 98 revertants/mg	TA 98 +S9 revertants/mg	Sampling sites
PM10					
Spontaneous	19	24	19	24	
12 June	1.2	1.0	39.7	36.9	1A
15 November	56.0	42.0	239.2	212.5	
12 June	2.7	1.8	59.3	39.3	P1
6 November	28.8	18.7	261.9	169.8	
13 June	3.0	1.9	62.0	39.0	P2
7 November	73.7	21.7	562.4	165.5	
14 June	2.7	.2	45.1	37.4	C
8 November	29.7	13.9	312.1	146.1	
15 June	3.2	3.0	56.8	53.6	R
9 November	60.6	38.1	555.9	349.2	
21 June	3.5	3.4	44.0	42.8	S
14 November	76.0	62.4	1036.1	751.8	
26 June	4.7	1.6	72.7	25.1	B
15 November	75.8	37.3	852.1	419.1	
PM2.5					
12 June	3.4	0.6	161.4	56.9	1B
15 November	63.9	31.0	769.8	373.3	
12 June	1.4	1.5	77.8	80.7	P1
6 November	25.0	15.6	480.8	300.4	
13 June	2.2	1.5	111.7	77.4	P2
7 November	27.5	10.9	416.1	165.7	
14 June	2.2	2.1	100.0	95.3	C
8 November	22.1	17.9	401.7	325.8	
15 June	3.9	1.7	164.0	69.1	R
9 November	36.1	24.9	645.1	443.9	
21 June	1.5	2.3	61.6	93.0	S
14 November	24.7	19.0	548.5	422.6	
26 June	2.6	0.8	153.6	49.0	B
15 November	22.1	15.3	452.6	313.2	

R artificial turf at Rivermosso, C artificial turf at Carrara, P1 artificial turf at Pellerina, P2 football field clay, B artificial turf at Barracuda, S artificial turf at Passo Buole

Summary of the Ames test results: Mean spontaneous Salmonella revertants and mean net revertants per m^3 sampled air and per µg particles

benzo[*a*]anthracene were the more abundant PAHs both on the football fields and at the urban site. The percentage ratio between the amount of total PAHs and the amount of PM10 or PM2.5 on which they were adsorbed was 10.4 % ± 5.1 % and 15.8 % ± 7.6 %, respectively. This ratio confirmed that in general for the football fields, the highest concentration of PAHs was on PM2.5.

Mutagenicity

Data were expressed as the average number of revertants per plate from the triplicate determinations. Table 4 lists the results obtained from the study tests. Extracts from airborne particulate matter collected on football fields and at urban sites in Torino showed low mean mutagenicity to *S. typhimurium* strain TA98 with and without metabolic activation (S9 mix). Compared with the spontaneous revertants, a greater effect was recorded with TA98 without S9 both for PM10 and for PM2.5. The mutagenic characteristics showed a seasonal trend and were found to be significantly different for the two sampling periods for both PM2.5 and PM10. The mutagenicity at the urban PM sites could be assessed for only 1 day of sampling. In June, on the football fields, the mean mutagenicity for PM2.5 was 111.4 ± 40.7 and 77.4 ± 17.0 revertants/mg for TA98 and TA98 + S9, respectively. The mean mutagenicity for PM10 was 56.6 ± 10.8 and 39.5 ± 9.2 revertants/mg for TA98 and TA98 + S9, respectively. In November, on the football fields, the mean mutagenicity for PM2.5 was 490.8 ± 91.9 and 328.6 ± 99.7 revertants/mg for TA98 and TA98 + S9, respectively. The mean mutagenicity for PM10 was 576.7 ± 268.5 and 333.6 ± 233.5 revertants/mg for TA98 and TA98 + S9, respectively. PM2.5 mutagenicity was greater at the urban sites. Considering the single values, TA 98 + S9 mutagenicity was greater on the R and Passo Buole (S) football fields. These fields were characterised by traffic and/or industrial emissions in the surrounding area. PM10 mutagenicity was greater on the football fields, especially on fields characterised by traffic and/or industrial emissions in the surrounding area.

Conclusion

This environmental analysis showed that PM fractions from artificial turfs often had concentrations equal to those found at urban stations during both warm and cold periods. In general, monitoring of PM10 and of PM2.5 in Torino showed concentrations that were frequently greater than the daily (50 and 20 μg/m^3, respectively) quality targets (Air Quality Directive 2008/50/CE), especially during winter sampling periods. Comparison between the artificial field and a clay field (Pellerina 1 [P1] and Pellerina 2 [P2],

respectively) showed slightly greater values for the latter, especially on cold days, but this situation was also different in urban areas on the two different sampling days. Lifting of the clay during sports games probably tends to increase the observed values of particulates. There were no differences in concentrations of PM linked to the age or type of the field (black used tires [UT] or thermoplastic) with respect to the different sampling days. The PM2.5 ratio and PM10 ratio on the football fields was comparable with the ratio at the urban sites. The ratio was between 0.4 and 0.8 (values closer to 0.8 indicate a situation more important for the respirable fraction). Especially during winter, the situation becomes more critical at the urban sites, reflecting the growing influence of fine components.

The concentration of BTX on the monitored football fields was constant and comparable with urban levels or at least reflects a normal situation relative to the urban pollution source of motor vehicles (the only exception is the concentration of BTX during the first sampling period in P1; that value was greater than both the other fields and at urban stations, probably because the gates at that field had been painted during the days before sampling). In general, benzene and toluene values were much lower than at the urban sites. There were no substantial differences in the concentrations of aromatic hydrocarbons related to age of the field or the type of field (black UT or thermoplastic) with respect to the different sampling days and even taking into account the few cases analysed, the condition of "use," and the temperatures. The T/B ratio was always comparable with normal urban conditions at all sites considered. Some studies showed that when this ratio assumes values >2, the pollution can be assumed to come from traffic (Valerio et al. 2005).

The concentration of PAHs on the monitored football fields, both PM10 and on PM2.5, were comparable with urban levels for the two different periods of sampling. With respect to the warm sampling, benzo[*b*]fluoranthene + benzo[*k*]fluoranthene were regarded as characteristic of PAH emissions from the combustion of gasoline in vehicles. Benzo[*ghi*]perylene (after pyrene) was considered characteristic of emissions from tire wear and asphalt (Pengchai et al. 2005). These PAHs were also present on the clay field; thus, probably because the fields were without on-field activity, these values could be attributable to traffic in the surrounding streets. In the cold sampling period, benzo[*b*]fluoranthene + benzo[*k*]fluoranthene were present at all fields and at the highest percentage compared with other PAHs. The same consideration was true for benzo[*a*]anthracene (characteristic of PAH emissions from combustion of gasoline in vehicles). Pyrene and benzo[*ghi*]perylene were also present on the clay field. Because the fields were used, these values could therefore be attributed to traffic on the surrounding streets. The

concentration ratios of all PAHs versus benzo[*a*]pyrene were found to be in the normal ranges observed in urban areas (Menichini et al. 1999).

In Italy, during the warm season, the total PAH concentrations at a traffic site range between 1 and 4 ng/m^3. In background, the values decrease between 0.1 and 1 ng/m^3 (Menichini and Monfredini 2006; Istituto Superiore per la Protezione e la Ricerca Ambientale [ISPRA] 2010). On the monitored fields, total PAH values ranging from <0.1 to 0.6 ng/m^3 were observed. During the cold season, total PAH concentrations at a traffic site ranged between 3 and 13 ng/m^3, whereas at a background site, values ranged between 1 and 5 ng/m^3. On the monitored fields, total PAH values ranging from 2.8 and 15.5 ng/m^3 were observed (Menichini and Monfredini 2006; ISPRA 2010). The PAHs exhibited a normal urban profile during the sampling periods considered. The concentrations measured on the field were substantially equal to the urban concentrations measured close to the field, and the contribution of PAHs released from the granular material was likely negligible. There were no differences in the concentrations of PAH linked to the age type of the fields (black UT or thermoplastic) with respect to the different sampling days. In our investigation, the highest percentage ratio between the amount of total PAHs and the amount of PM on which they were adsorbed was reported for PM2.5, and the PM2.5/PM10 concentration ratio was greater for urban sites. Presumably, the exposure to PAHs would be greater in the city than on the football fields. Because the target PAHs were present in air as particle-bound, their highest concentrations were expected to occur close to the points where the turf is stressed, thus causing particles to be released (Menichini et al. 2011). However, the high-volume air sampler was located at the top of the penalty area, so the measurements could underestimate the actual concentrations to which the athletes were exposed. The use of personal air samplers seems to be a suitable procedure to estimate the actual concentrations to which the athletes are exposed. However, a recent study emphasised that the uptake of PAH by football players active on artificial grounds with rubber crumb infill is minimal. If there were any exposure, then the uptake would be limited and within the range of uptake of PAH from environmental sources and/or diet (van Rooij and Jongeneelen 2010).

In the present monitoring study, the mutagenicity of football-field PM10 was greater, whereas the mutagenicity of football-field PM2.5 was lower compared with the urban site. In general, on artificial football fields, in both June and in November, mean values were comparable with values reported in other studies for urban sites (Cassoni et al. 2004; Claxton et al. 2004; Gilli et al. 2007a, b).

In the present study, on the basis of the air monitoring and despite the small number of cases analysed, the

concentrations of PM, BTX, PAHs as well as mutagenicity on artificial football fields showed a normal urban trend in the periods considered. No significant differences were found between artificial football fields and urban sites. No differences were found between artificial football fields and "natural" football fields. There would not be any more risk on an artificial turf football field than there would be in the rest of the city. Further work will be necessary to assess the actual scenarios of exposure by inhalation and the corresponding risks.

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