Effect of Crumb Rubber on the Wear Tolerance of Korean Lawngrass

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폐타이어 칩이 한국들잔디의 내답압성에 미치는 영향

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ABSTRACT

The objective of this study was to evaluate the effects of crumb rubber recycled from used tires as a soil incorporation and topdressing materials on a trafficked Korean lawngrass 'Zenith' (*Zoysia japonica*). In Exp 1, incorporation treatments included three particle sizes (PS: coarse = 4~6.35 mm, medium = 2~4 mm, and fine = less than 2 mm in diameter) and two incorporation rate (IR: 10 and 20%). Wear treatments were applied 30 passes per day by compactor weights being 60 kg with soccer shoes. Topdressing treatments included three PS and two topdressing depth (TD; 5 and 10 mm). Wear treatments were the same as described in Exp 1. In Exp 1, the treatment with medium PS + IR 20 resulted in the tendency to have high total clipping yield. There was no significant difference in clipping yield, turfgrass visual color, coverage, and root length among the treatments. Compared to control, tissue Zn levels increased about 6.5-fold by the treatments. The treatment with fine PS + IR 20 caused a less peak deceleration than coarse PS + IR 10. Total porosity, air-filled porosity, and capillary porosity increased with fine PS + IR 20. In Exp 2, compared to controls, however, there was a difference in turfgrass visual color after the termination of traffic treatment. There was no difference in root length. The treatment with fine PS + TD 10 resulted in the highest total clipping yield. As a result of soil physical analysis, soil penetration resistance was reduced by the treatments. The treatment with coarse PS resulted in a less peak deceleration than fine PS. In conclusion, turfgrass growth was increased by crumb rubber incorporation which enhanced soil physical properties. The crumb rubber topdressing was able to cushion the crown tissue area while still providing a smooth and uniform surface, improve overall turfgrass quality, and reduce compaction.

Key words: crumb rubber, soil compaction, soil incorporation, topdressing, traffic, turfgrass, wear resistance, *Zoysia japonica*

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INTRODUCTION

Turfgrass areas in athletic fields are the most difficult to manage. During the utilization and enjoyment of turfgrass, they receive intense traffic and may sustain serious damage on a regular basis (Christians, 1998). A second for less obvious effect occurs to the underlying soil that is sometimes referred to as the 'hidden effect.'

Most compaction in turfgrass situations occurs within 2 to 3 inch of the soil surface, with the highest soil densities occurring in the upper inch. The wear tolerance of a turfgrass varies depending on the turfgrass species, intensity of culture, environment, and intensity and type of traffic. Depending on the nature of the traffic, wear can be manifested as injury from pressure, abrasion, scuffing, or tearing (Beard, 1973). Alleviation of soil compaction caused by traffic can be accomplished by several methods including soil cultivation. Method of cultivation include coring (hollow tine, solid tine, and drill), slicing, spiking, grooving, forking, and subaerification. On area that received intensive traffic, soil modifications may be required. Partial modifications can be achieved by the addition of a physical amendment to the existing soil. Sand, calcined clay, peats, and other amendment are used (Carrow and Petrovic., 1992). Some turfgrass manager are starting to use compost and compost amended with bulking agent, such as aged crumb rubber from used tires or wood chips, as cost-effective alternatives. Since the rubber recycling was introduced to the turfgrass industry, ways have been improved for the incorporation of the rubber into the soil profile. Crumb rubber is typically the rubber particle used for topdressing turfgrass (Salmond and Minner, 1998).

Potential benefits of rubber amended soil for turfgrass performance and health include increasing porosity, drainage, and resiliency of the soil. Thus, plant growth is not inhibited by waterlogging or compaction, reducing the probability of impacted- related injuries to athletes and thoroughbreds, long-lasting soil enhancement for 10-25 years, economical and longer-lasting than organic amendments, and beneficial recycling of resources (Groenevelt and Grunthal, 1998).

The objective of this study was to evaluate the effect of crumb rubber from recycled tires on the growth of 'Zenith' zoysiagrass, and physical and chemical properties of soil as a soil incorporation and topdressing material into turfgrass under highly trafficked condition.

MATERIALS AND METHODS

Crumb rubber incorporation experiments were conducted at the College of Agriculture & Life Science, Seoul National University. Crumb rubber processed from waste tire was obtained from a Korea Resources Recovery & Reutilization Corporation. Plot sizes were a circle with 0.5 m diameter. Plot frame was constructed by corrugated polyethylene pipes. The incorporation treatments were three types and two rates of crumb rubber and untreated control. The crumb rubber particles were screened with 5 and 10 mesh U.S. Tyler sieve (Chunggye Industrial Co., Seoul). The rubber treatments consisted of coarse (5 mesh-1/4 in mesh: 4-6.35 mm), medium (5-10 mesh: 2-4 mm) and fine (greater than 10 mesh<: 2 mm) crumb size. Crumb rubbers were incorporated to the depth of 20 cm with the incorporation rates at 10 and 20%. Each rate was split into application made on 19 May, 2001. Plots were covered with Korean lawngrass 'Zenith'. They were irrigated to ensure their active growth and fertilized with 50 kg · ha^{-1} (14-10-12 N-P-K) in June, July, and August of 2001. Crumb rubber was incorporated in a randomized complete block design with three replications on a 100% sand. Crumb rubber topdressing experiment was conducted at the Suwon World Cup Training Field, Suwon from Sept. 8, 2001. Crumb rubber was topdressed in a randomized complete block design with three replications on a pre-established 'Zenith' Korean lawngrass field. Plot size was 1.0×1.0 m for each treatment. Topdressing treatments were three types and two depths of crumb rubber with untreated control. The crumb rubbers were topdressed at depth of 5 and 10 mm. The topdressing rates at 10 mm depth were 44.0 M/T · ha^{-1}, 42.3 M/T · ha^{-1}, and 42.3 M/T · ha^{-1} for coarse, medium, and fine size, respectively. Crumb rubber was topdressed by hand carefully for even distribution on a 'Zenith' Korean lawngrass. Turfgrass was conventionally managed. Traffic treatment was applied across the plots with the soccer shoes. Compactor weighs 60 kg. Turfgrass was subjected to 30 passes per day from Sept. 8 to Sept. 28, 2001, for a total of 540 passes.

Soil penetration resistance was measured with a hand-driven cone penetrometer (CP20 Penetrometer, Agridry Rimik Pty Ltd.). Measurements were taken in 20 mm increments to 100 mm below the soil surface. The penetration resistance value was a average of three insertion readings. Surface data was collected. Impact absorption characteristics, an indicator of surface hardness, was measured with a Clegg impact soil tester (Lafayette Instruments Co., Lafayette, IN) (Clegg, 1976). The peak deceleration was a reading of three drops of a 4.5 kg hammer from a height of 45 cm. Penetrometer and Clegg impact soil tester measurements were taken on Sept. 8, 18, and 28, 2001. Bulk density, total porosity, air-filled porosity, capillary porosity, maximum water holding capacity determinations were made from a single core (3.0 cm diam×5.3 cm). Bulk density was determined by the gravimetric method. Infiltration rate was measured using the constant head method, as described by Klute and Dirksen (1986). Field capacity was determined with the pF-curve determination with ceramic plates (Eijkelkamp, Giesbeek, The Netherlands). Soil samples were placed in plastic rings on the ceramic plates for an overnight saturation to ensure air-free samples. The saturated soil samples were placed in a 1/3 bar pressure membrane for 24 h and weighed (W1). The same samples were dried in an oven at 105℃ for 24 h and later weighed (W2). The moisture content at field capacity was obtained as the following equation:

$$FC(\%) = \frac{W1 - W2}{W2} \times 100$$

Total nitrogen was determined by the Kjeldahl method. Available phosphorus was extracted with the Lancaster's extractant (NIAST, 2000). Exchangeable calcium, magnesium, sodium, and potassium aluminum, cadmium, copper, lead, iron, manganese, and zinc concentrations were determined by an inductively coupled plasma emission absorption spectrophotometer (ICPS-1000Ⅳ, Shimadzu, Japan). Organic matter contents were determined using the Tyurin method (NIAST, 2000). Electrical conductivity (EC) and pH were measured by EC meter (CM 21P, TOA Electronics Ltd., Japan) and pH meter (HM-120, TOA Electronics Ltd., Japan). CEC was determined using the Brown method (Brown and Warncke, 1988). Clipping yields were taken from the trafficked turfgrass plots on Sept. 13, 18, 24 and 28, using hedge shears. Fresh weight was measured, and then the samples were dried for 48 h at 85℃ for dry weight measurement. Elemental (P, K, Na, Ca, Mg, Fe, Mn, Cu, Pb, Cd, and Zn) concentrations were determined by an inductively coupled plasma emission absorption spectrophotometer. Total N was determined by the Kjeldahl method. Root length was measured at the end of the experiment. Roots were sampled with auger (100 mm diameter). Turfgrass color was visually evaluated on a scale of 1-9 (1 = brown or yellow; 9 = dark green). Turfgrass coverage was visually evaluated on percent base. Surface (canopy) and subsurface (25, and 65 mm in depth) soil temperatures were recorded with a portable infrared thermometer (Rayunger® ST™, Raytek), and a portable thermometer (HI 8424C, HI 7669AW, Hanna instrument), respectively. Soil temperature data were the average from Sept. 8 to 28 in 2001.

Data were analyzed by using general linear model (GLM) procedure of SAS software (SAS Institute Inc., Cary, NC, 1989). The mean values were compared using the least significant difference (LSD). For comparison between means, Duncan's multiple range test (Duncan, 1955) was applied in interaction tables.

RESULTS AND DISCUSSION

Crumb rubber incorporation

Visual color, coverage and growth characteristics of a trafficked Korean lawngrass 'Zenith' are presented in Tables 1 and 2. There was no statistically significant difference in visual color as affected by crumb rubber incorporation rates (IR) and crumb rubber particle size (PS). However, the treatment with 10% of coarse crumb rubber resulted in the best visual color (Table 1). Visual color and turfgrass cover were reduced with increased traffic regardless of PS and IR. The largest turfgrass cover of 60.0 and 58.3% was found after 21 days of compaction when the largest crumb rubber particle size was incorporated. Root length was not affected by the treatments. There was no statistically significant difference in clipping yield among the treatments because topsoil was soft at the beginning of traffic treatment. Clipping yield declined with traffic. The best total clipping yield was obtained when 20% of medium crumb rubber was incorporated (Table 2). Decline in turfgrass quality and clipping yield as traffic increased was similar to the trend observed by other investigators (Dunn et al., 1994; Sills and Carrow, 1983). Compared to control, total N, P, K, Ca, Mg, and Na contents were decreased because crumb rubber contained much more inorganic elements. Al, Fe, and Mn were not increased by IR whereas Cu and Zn increased (Table 3). Compared to controls, tissue Zn levels increased 3.6-, 5.0-, and 6.3-fold in IR 20 of

Table 1. Effects of crumb rubber incorporation into the soil on visual color and coverage in a trafficked Korean lawngrass 'Zenith'.

Treatment		Visual color^z					Coverage (%)					
PS^y	IR^x (%)	Sep. 13	Sep. 18	Sep. 24	Sep. 28	Mean	Sep. 8	Sep. 13	Sep. 18	Sep. 24	Sep. 28	Mean
Coarse	10	7.7a^w	7.7a	6.8a	7.0a	7.30a	83.3a	76.7a	70.0a	63.3a	60.0a	70.7a
	20	7.0a	7.0ab	6.8a	6.3a	6.80ab	88.3a	75.0a	70.0a	63.3a	58.3a	71.0a
Medium	10	7.2a	6.7b	6.7a	6.2a	6.67ab	81.7a	75.0a	68.3a	63.3a	55.0a	68.7a
	20	6.8a	6.5b	6.2a	6.7a	6.54b	83.3a	70.0a	58.3a	50.0a	51.7a	62.7a
Fine	10	6.7a	6.2b	6.7a	6.3a	6.42b	78.3a	60.0a	56.7a	53.3a	50.0a	59.7a
	20	7.0a	6.7b	6.0a	6.0a	6.42b	85.0a	68.3a	61.7a	51.7a	48.2a	63.0a
Control		7.0a	6.5b	6.2a	6.3a	6.50b	76.7a	65.0a	55.0a	51.7a	46.7a	59.0a
Statistical significance^v												
PS		NS	*	NS	NS	*	NS	NS.	NS	NS	NS	NS
IR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PS×IR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{z}Visual turf color was evaluated with 1-9 scale (1 = brown or yellow, 9 = dark green).
^{y}Particle size.
^{x}Incorporation rate.
^{w}Means followed by the same letter within a column are not significantly different (P = 0.05) according to Duncan's multiple range test.
^{v}NS,* Non-significant or significant at P = 0.05.

Table 2. Effects of crumb rubber incorporation into the soil on clipping yield in a trafficked Korean lawngrass Zenith'.

Treatment		Clipping yield									
		Fresh weight (g · m^{-2})					Dry weight (g · m^{-2})				
PS^z	IR^y (%)	Sep. 13	Sep. 18	Sep. 24	Sep. 28	Total	Sep. 13	Sep. 18	Sep. 24	Sep. 28	Total
Coarse	10	11.68a^x	4.25a	2.51a	0.51a	14.87a	4.62a	1.47a	0.91a	0.20a	5.64a
	20	10.20a	5.96a	2.14a	0.57a	14.81a	3.80a	2.14a	0.77a	0.20a	5.43a
Medium	10	11.66a	4.67a	2.96a	0.99a	15.92a	4.25a	1.68a	1.07a	0.37a	5.78a
	20	11.87a	5.05a	2.92a	0.86a	16.25a	4.49a	1.86a	1.02a	0.31a	6.03a
Fine	10	9.46a	4.50a	2.44a	0.52a	13.29a	3.63a	1.60a	0.84a	0.20a	4.92a
	20	10.37a	4.40a	2.19a	0.63a	13.81a	3.97a	1.60a	0.82a	0.23a	5.20a
Control		8.55a	4.17a	2.56a	0.58a	12.45a	3.58a	1.51a	0.93a	0.21a	4.90a
Statistical significance^w											
PS		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
IR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
PS×IR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

^{z}Particle size.
^{y}Incorporation rate.
^{w}Means followed by the same letter within a column are not significantly different (P = 0.05) according to Duncan's multiple range test.
^{x}NS Non-significant.

coarse, medium, and fine PS, respectively (Table 3). Crumb rubber significantly increased the concentration of Zn in turfgrass clippings (Groenevelt and Grunthal, 1998).

Table 3. Effects of crumb rubber incorporation on content of microelements in Korean lawngrass 'Zenith'.

Treatment		Microelement contents				
PS[z]	IR[y] (%)	Al	Cu	Fe	Mn	Zn
				$(mg \cdot kg^{-1})$		
Coarse	10	424a[w]	2.52a	302a	87a	82d
	20	514a	2.44a	304a	102a	192bc
Medium	10	465a	2.43a	304a	92a	151cd
	20	392a	8.71a	249a	106a	267ab
Fine	10	417a	2.14a	270a	67a	236bc
	20	410a	2.73a	271a	77a	336a
Control		674a	2.34a	375a	92a	53d
Statistical significance[x]						
PS		NS	NS	NS	NS	***
IR		NS	NS	NS	NS	***
PS×IR		NS	NS	NS	NS	NS

[z]Particle size.
[y]Incorporation rate.
[x]NS,*** Non-significant or significant at $P = 0.001$.
[w]Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.
Note: Plant samples were collected at 133 days after crumb rubber treatment.

However, elevated concentration was not sufficient to produce Zn toxicity in turfgrass. Treatments consisting of an acidic soil and crumb rubber elevated the levels of Zn, B and Na. These effects were negated by the addition of lime to the soil mixture. Turner (1993) reported no response of 'Penncross' creeping bentgrass to increasing levels of Zn, and Deal and Engel (1965) reported no change in Kentucky bluegrass sod color and top growth when treated with Zn. However, Deal and Engel (1965) reported an increase in root production of Kentucky bluegrass sod as Zn treatment levels increased. Wu et al. (1981) described no decline in the root production of two hybrid bermudagrass (*Cynodon dactylon* L. *transvaalensis BurttDavy*) exposed to Zn at 50 $mg \cdot L^{-1}$. Xu and Mancino (2001) described reduced turfgrass color and growth of creeping bentgrass, vegetative annual bluegrass, flowering annual bluegrass as shoot tissue Zn concentration increased above 109.0, 203.0, 142.3 $mg \cdot kg^{-1}$, respectively. Furthermore, the accumulation of Zn to high tissue levels indicates that all but the most Zn-tolerant plants might suffer toxicity when grown in rubber-containing media (Newman et al., 1997).

Penetration resistance measured on Sept. 8 at the 0-20, 20-40, 60-80, and 80-100 mm depth differed one another among treatments (Table 4). On Sept. 8, penetration resistance was affected by IR. There were significant interactions on Sept. 18, between crumb rubber rate and particle size. On Sept. 28 penetration resistance was only affected by PS. Soil penetration resistance increased with depth and changed over time (Limon-Ortega et al., 2002). The treatment with fine PS had a less penetration resistance than coarse PS. The treatment

Table 4. Effects of crumb rubber incorporation on penetration resistance values of soil 0-100 mm deep in a trafficked Korean lawngrass 'Zenith'.

Treatment		Soil depth (mm)				
PS[z]	IR[y] (%)	0-20	20-40	40-60	60-80	80-100
				Penetration resistance (kPa)		
				Sep. 8[x]		
Coarse	10	611a[v]	638a	646a	671a	664a
	20	425c	482bc	509bc	541bc	594ab
Medium	10	486bc	473bc	499bc	530bc	550bc
	20	470bc	497bc	525bc	563bc	583ab
Fine	10	588ab	566ab	587ab	607ab	583ab
	20	444c	447c	460c	480c	504bc
Control		487bc	482bc	501bc	497c	481c
Statistical significance[w]						
PS		NS	NS	NS	NS	*
IR		***	**	**	**	NS
PS×IR		NS	*	*	*	NS
				Sep. 18		
Coarse	10	1028a	1010a	1003a	993a	984a
	20	1010a	997a	954ab	927ab	892b
Medium	10	919b	896b	874ab	855bc	848b
	20	918b	894b	857c	835c	829bc
Fine	10	936b	919b	879ab	850bc	833bc
	20	792c	774c	716d	684d	663d
Control		892b	864b	821c	799c	753c
Statistical significance						
PS		***	***	***	***	***
IR		**	*	**	***	***
PS×IR		**	**	*	*	NS
				Sep. 28		
Coarse	10	1048a	1086a	1077a	1083a	1034a
	20	1043a	1031a	999a	972b	1029a
Medium	10	870bc	883bc	838bc	829cd	872b
	20	923bc	900bc	860bc	854cd	890b
Fine	10	893bc	898bc	870bc	836cd	833b
	20	847c	819c	776c	737d	709c
Control		962ab	943b	906b	888bc	839b
Statistical significance						
PS		***	***	***	***	***
IR		NS	NS	NS	NS	NS
PS×IR		NS	NS	NS	NS	NS

[z]Particle size.
[y]Incorporation rate.
[x]Initial penetration resistance before traffic.
[w]NS,*,**,*** Non-significant or significant at $P = 0.05$, 0.01, and 0.001, respectively.
[v]Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

with 20% of crumb rubber had a less penetration resistance than 10% of crumb rubber. The treatment with IR 20 of fine PS resulted in soft soil. There was no statistically significant difference in peak deceleration values among crumb rubber sizes,

Table 5. Effects of crumb rubber incorporation into the soil on peak deceleration in a trafficked Korean lawngrass 'Zenith'.

Treatment		Peak deceleration (Gmax)		
PS[z]	IR[y] (%)	Sep. 8[x]	Sep. 18	Sep. 28
Coarse	10	5.52ab[v]	7.20a	7.32a
	20	5.06c	6.82ab	7.26a
Medium	10	5.18bc	6.83ab	7.01a
	20	5.33abc	6.42bc	6.28b
Fine	10	5.37abc	6.98ab	7.04a
	20	5.06c	6.12c	5.98b
Control		5.58a	7.27a	7.60a
Statistical significance[w]				
PS		NS	NS	***
IR		*	**	***
PS×IR		*	NS	NS

[z]Particle size.
[y]Incorporation rate.
[x]Initial penetration resistance before traffic.
[w]NS,*,**,*** Non-significant or significant at $P = 0.05$, 0.01, and 0.001, respectively.
[v]Means followed by the same letter within a column are notsignificantly different ($P = 0.05$) according to Duncan's multiple range test.

except on Sept. 28 (Table. 5). Peak deceleration was the lowest at fine PS+IR 20 treatment. Peak deceleration was increased with increased traffic regardless of PS and IR. Peak deceleration (Gmax) is a measure of the impact energy absorbed by the surface.

The higher the peak deceleration value, the more energy being returned to the object contacting the surface, or the harder the surface. The shorter the time period, the greater the deceleration and the harder the tested surface (Clegg, 1978). In Sept. 28, peak deceleration was affected by IR and PS. The treatment with IR 20 had a less peak deceleration than that of IR 10, and fine PS had a less peak deceleration than coarse PS. Table 5 shows that treatments with IR 20 of medium PS and fine PS had low peak deceleration value. Soft surfaces were associated with soils amended with crumb rubber (Boniak at al., 2001). These results indicated that crumb rubber could enhance the resiliency of the soil and it may be helpful in easing potential sports injuries on the high clay content athletic fields, particularly if the soil is dry.

Infiltration rate, bulk density, total porosity, air-filled porosity, capillary porosity, and maximum water holding capacity data are shown in Table 6. Infiltration rate was not different among the treatments. The treatment with IR 20 of fine PS decreased bulk density and increased capillary porosity. The treatment with IR 10 of fine PS increased air-filled porosity and decreased capillary porosity. Control had the best maximum water holding capacity. Soil temperatures were not affected by crumb rubber incorporations since they were placed underneath the turfgrass mat and thereby blocked from solar radiation. Results showed that the pH of the soil ranged from 5.0 to 5.8. The cation exchange capacities (CEC) and EC of the soil mixes were almost the same as those of the control treatment. Statistical analysis obtained by the Duncan's multiple range test indicated that Cu, Fe, and Zn were significantly different among the treatments (Table 7). Soil mix with crumb rubber had Zn content which was significantly higher than the control (Newman et al., 1997). 'Zenith' Korean lawngrass was grown in crumb rubber incorporation treatment without reducing plant quality.

Crumb rubber topdressing

Turfgrass visual color and growth characteristics of a trafficked 'Zenith' Korean

Table 6. Effects of crumb rubber incorporation into the soil on physical properties of soil after compaction.

Treatment		Infiltration rate	Bulk density	Total porosity	Air-filled porosity	Capillary porosity	Maximum water holding capacity
PS[z]	IR[y] (%)	($cm \cdot s^{-1}$)	($g \cdot cm^{-3}$)	(%)	(%)	(%)	(%)
Coarse	10	0.02a[w]	1.47ab	44.64ab	8.94c	35.70a	3.71ab
	20	0.02a	1.44ab	45.47ab	9.44bc	36.02a	3.41b
Medium	10	0.01a	1.47ab	44.57ab	10.40abc	34.17a	3.83ab
	20	0.01a	1.43ab	46.01ab	10.33abc	35.68a	3.44b
Fine	10	0.02a	1.50a	43.45b	11.18a	32.27a	3.77ab
	20	0.02a	1.40b	46.95a	10.86ab	36.09a	3.58ab
Control		0.02a	1.46ab	44.67ab	9.32bc	35.35a	4.79a
Statistical significance[x]							
PS		NS	NS	NS	**	NS	NS
IR		NS	*	*	NS	NS	NS
PS×IR		NS	NS	NS	NS	NS	NS

[z]Particle size.
[y]Incorporation rate.
[x]NS,*,** Non-significant or significant at $P = 0.05$, and 0.01, respectively.
[w]Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

Table 7. Effects of crumb rubber incorporation into the soil on the microelements content in soil after compaction.

Treatment		Microelement contents						
PS[z]	IR[y] (%)	Al	Cd	Cu	Fe	Mn	Pb	Zn
					($mg \cdot kg^{-1}$)			
Coarse	10	198.3a[w]	0a	1.9d	50.2abc	39.8ab	0a	26.7a
	20	199.9a	0a	3.3bc	70.8a	47.2a	0a	28.8a
Medium	10	199.9a	0a	2.9c	65.3ab	46.8a	0a	28.8a
	20	194.6ab	0a	3.8b	67.2ab	47.3a	0a	28.8a
Fine	10	180.3ab	0a	3.6bc	45.2bc	35.9ab	0a	28.8a
	20	186.7ab	0a	6.5a	69.6a	40.5ab	0a	28.8a
Control		169.3b	0a	1.0e	36.0c	33.1b	0a	4.4b
Statistical significance[x]								
PS		NS	NS	***	*	NS	NS	NS
IR		NS	NS	***	NS	NS	NS	NS
PS×IR		NS	NS	**	NS	NS	NS	NS

[z]Particle size.
[y]Incorporation rate.
[x]NS,*,**,*** Non-significant or significant at $P = 0.05$, 0.01, and 0.001, respectively.
[w]Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

lawngrass are presented in Table 8 and 9. There were statistically significant differences in visual color as affected by crumb rubber topdressing depth (TD) and crumb rubber particle size (PS) on Sept. 28. The treatment with 10 mm depth of fine crumb rubber could maintain the best visual color (Table 8). Turfgrass visual color was less deteriorated by the crumb rubber treatments. Visual color was deteriorated with increased traffic regardless of PS and TD. Root length was not affected by the treatments. There was statistically significant difference in clipping yield between treat-

Table 8. Effects of crumb rubber topdressing on visual color in a trafficked Korean lawngrass 'Zenith'.

Treatment		Visual color[z]				
PS[y]	TD[x] (mm)	Sep. 13	Sep. 18	Sep. 24	Sep. 28	Mean
Coarse	5	7.7a[v]	7.2a	8.3a	9.0a	8.00a
	10	7.8a	7.7a	8.0a	8.0b	7.79a
Medium	5	7.7a	7.2a	8.3a	9.0a	7.88a
	10	7.6a	7.3a	8.0a	8.7a	8.01a
Fine	5	7.3a	7.2a	8.3a	9.0a	8.00a
	10	7.5a	7.7a	8.3a	9.0a	8.07a
Control		6.6b	6.0b	6.3b	7.0c	6.38b
Statistical significance[w]						
PS		NS	NS	NS	**	NS
TD		NS	NS	NS	***	NS
PS×TD		NS	NS	NS	**	NS

[z]9 = dark green; 1 = brown or yellow (See Table 1).
[y]Particle size.
[x]Topdressing depth.
[w]NS,**,*** Non-significant or significant at $P = 0.01$, and 0.001, respectively.
[v]Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

Table 9. Effects of crumb rubber topdressing on clipping yield in a trafficked Korean lawngrass 'Zenith'.

Treatment		Clipping yield									
PS[z]	TD[y] (mm)	Fresh weight (g · m^{-2})					Dry weight (g · m^{-2})				
		Sep. 13	Sep. 18	Sep. 24	Sep. 28	Total	Sep. 13	Sep. 18	Sep. 24	Sep. 28	Total
Coarse	5	26.96b[w]	28.77a	14.12b	7.49b	77.34c	10.82a	10.21a	5.39b	2.93b	29.35c
	10	19.08c	23.99a	22.26a	8.47b	73.80c	7.53b	8.94a	7.97a	3.05b	27.49c
Medium	5	33.76ab	27.33a	15.41b	7.76b	84.26abc	13.04a	10.24a	5.75b	3.08b	32.10ab
	10	28.32b	35.07a	24.54a	11.09a	99.02ab	11.92a	12.93a	8.69a	3.96a	37.51a
Fine	5	31.92ab	38.98a	12.95b	7.75b	91.60abc	11.96a	13.85a	4.80b	3.00b	33.61ab
	10	33.03ab	40.17a	21.60a	11.72a	106.52a	12.45a	14.49a	7.67a	4.23a	38.84a
Control		36.21a	20.59a	10.25b	2.96c	70.01c	13.64a	8.26a	4.06b	1.22c	27.18b
Statistical significance[x]											
PS		**	NS	NS	*	**	**	NS	NS	NS	**
IR		*	NS	***	***	NS	NS	NS	***	**	NS
PS×IR		NS	NS	NS	NS	NS	NS	NS	NS	NS	NS

[z]Particle size.
[y]Topdressing depth.
[x]NS,**,*** Non-significant or significant at $P = 0.01$, and 0.001, respectively.
[w]Means followed by the same letter within a column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

ments except on Sept. 18 (Table 9). Clipping yield declined with traffic. The treatment with 10 mm depth of fine crumb rubber had the highest total clipping yield. The decline in clipping yield as traffic increased was similar to the results observed by other investigators (Dunn et al, 1994, Sills and Carrow, 1983). Total nitrogen, Ca, Mg, Na, Al, Cu, Fe, Mn, and Zn contents with plant were not affected by the treatments, where as P, K. P contents were affected by PS. K contents were affected by TD.

Penetration resistance measured on Sept. 8 for the 0-20, 20-40, 60-80, and 80-100 mm soil profiles differed among treatments (Table 10). On Sept. 8 for 0-20 mm soil profile, penetration resistance was affected by TD. On Sept. 18 for the 20-80 mm penetration resistance was affected by PS. On Sept. 28, penetration resistance was not affected by treatments. There were no statistically significant difference in peak deceleration values among crumb rubber sizes, except on Sept. 18 and 28 (Table 11). On Sept. 18, peak deceleration values were affected by TD. In Sept. 28, peak deceleration values were affected by PS. The treatment with fine crumb rubber had a greater peak deceleration than coarse crumb rubber. These results indicated that crumb rubber could enhance the resiliency of the soil and it may be helpful in easing potential sports injuries on the high clay content athletic fields, particularly if the soil is dry. Infiltration rate, air-filled porosity, capillary porosity, and maximum water holding capacity were not affected by the treatments. However, bulk density and total porosity were affected by PS. Soil temperature was affected by TD at the surface and sub surface 25 mm (Table 12). Topdressing with 10 mm of crumb rubber resulted in higher soil temperature than 5 mm of crumb rubber. Results showed that the pH of the soil ranged from 6.4 to 7.4. The cation exchange capacities (CEC) and EC of the soil mixes were almost the same as that of the control treatment. Statistical analysis obtained by the Duncan's multiple range test indicated that there was no significant difference among the treatments. Results showed no significant difference ($P = 0.05$) in Total-N, P, K, Ca, Mg, Na, Al, Cd, Cu, Fe, Mn, Pb, OM, and Zn among the treatments, and the nutrients were not at toxic levels for plant growth.

Even though topdressing was more effective than incorporation in terms of relative clipping yield, since these researches were carried under different condition, it is difficult to conclude topdressing is better than soil incorporation and also, the effect of crumb rubber when both topdressed and soil incorporated is not clear. Therefore, further detailed research needs to be carried out separately or together.

In summary, turfgrass wear increased and soil physical properties declined as compaction increased. However, turfgrass growth was less deteriorated by crumb rubber incorporation which enhanced soil physical properties even under trafficked condition. The crumb rubber topdressing was able to cushion the crown tissue area while still providing a smooth and uniform surface, improve overall turfgrass quality, and reduce compaction. Soil surface temperature was increased by crumb rubber topdressing. The crumb rubber incorporation and topdressing offered a long-term solution

Table 10. Effects of crumb rubber topdressing on penetration resistance values of soil 0-100 mm deep in a trafficked Korean lawngrass 'Zenith'.

Treatment		Soil depth (mm)				
PS[z]	TD[y] (mm)	0-20	20-40	40-60	60-80	80-100
				Penetration resistance (kPa)		
				Sep. 8[x]		
Coarse	5	2902bc[v]	3444abc	3865a	3840a	4058a
	10	2682c	3166bc	3885a	3763a	3994a
Medium	5	3233ab	3643ab	3916a	4065a	3946a
	10	2856bc	3422bc	3989a	3839a	3743a
Fine	5	3141abc	3464abc	3770a	3790a	3858a
	10	2854bc	3409bc	3823a	4067a	4182a
Control		3446a	3885a	4008a	4070a	3956a
Statistical significance[w]						
PS		NS	NS	NS	NS	NS
TD		*	NS	NS	NS	NS
PS×TD		NS	NS	NS	NS	NS
				Sep. 18		
Coarse	5	3054ab	3436b	3730b	4021b	4208a
	10	3030b	3604ab	4169a	4549a	4616a
Medium	5	3375a	3908a	4268a	4323ab	4495a
	10	3102ab	3734ab	4137a	4376ab	4246a
Fine	5	3236ab	3556b	3904ab	3999b	4240a
	10	3149ab	3515b	3884ab	3978b	4373a
Control		3272ab	3685ab	3900ab	4159ab	4209a
Statistical significance						
PS		NS	*	*	*	NS
TD		NS	NS	NS	NS	NS
PS×TD		NS	NS	NS	NS	NS
				Sep. 28		
Coarse	5	3151a	3107b	3823ab	4067a	4144a
	10	2990a	3438ab	3947ab	4181a	4008a
Medium	5	3288a	3537ab	4101a	4260a	4115a
	10	2968a	3571ab	3886ab	4508a	4605a
Fine	5	3119a	3298b	3883ab	4030a	4247a
	10	3110a	3290b	3400b	4057a	4222a
Control		3165a	3813a	3561ab	4307a	4538a
Statistical significance						
PS		NS	NS	NS	NS	NS
TD		NS	NS	NS	NS	NS
PS×TD		NS	NS	NS	NS	NS

[z]Particle size.
[y]Topdressing rate.
[x]Initial penetration resistance before traffic.
[w]NS,* Non-significant or significant at $P = 0.05$.
[v]Means followed by the same letter within column are not significantly different ($P = 0.05$) according to Duncan's multiple range test.

to heavily used areas which normally receive compaction more frequently, and it will be also able to contribute to the turfgrass establishment and management.

Table 11. Effects of crumb rubber topdressing on peak deceleration in a trafficked Korean lawngrass 'Zenith'.

Treatment		Peak deceleration (Gmax)		
PS[z]	TD[y] (mm)	Sep[x]. 8	Sep. 18	Sep. 28
Coarse	5	9.84bc[v]	10.94b	10.45c
	10	9.99bc	11.13b	10.59c
Medium	5	10.31bc	11.76a	10.70bc
	10	9.71c	10.72b	10.88bc
Fine	5	10.56b	11.88a	11.90a
	10	10.04bc	10.99b	11.16abc
Control		11.53a	12.28a	11.58ab
Statistical significance[w]				
PS		NS	NS	**
TD		NS	**	NS
PS×TD		NS	*	NS

[z]Particle size.
[y]Topdressing depth.
[x]NS,*,** Non-significant or significant at $P=$ 0.05, and 0.01 respectively.
[w]NS,* Non-significant or significant at $P=0.05$.
[v]Means followed by the same letter within column are notsignificantly different ($P=0.05$) according to Duncan's multiple range test.

요 약

본 실험은 답압에 의한 스트레스를 경감시킬 목적으로 폐타이어 칩을 한국잔디 식재 토양내 혼합 및 표면 배토시 그 효과를 평가하고자 실시하였다. 일반적으로 잔디는 답압이 진행됨에 따라 잔디 마모와 토양물리성이 나빠져서 생육은 감소하지만 폐타이어 칩을 토양 내에 처리함으로써 토양경도, 표면 경도 등 토양물리성을 향상시키므로 생육을 향상시킬 수 있었으며, 토양 혼합처리는 가는 입자 20% 처리구에서 좋은 토양물리성을 보였다. 배토처리시에는 무처리구와·비교시 표면의 높은 온도와 더불어, 피복효과와 마모를 가장 많이 받는 줄기 밑부분을 보호해 줌으로써 잔디 생육을 향상시킬 수 있었으며, 굵은 입자 10cm 처리구에서 표면온도가 높았다. 무기질인 폐타이어 칩을 소량으로 토양 혼합 및 배토처리함으로써 장기적인 효과가 예상되므로 향후 잔디면 조성 및 관리시에 이용할 만한 가능성이 있다고 생각된다.

Table 12. Effects of crumb rubber topdressing on soil temperature in a trafficked Korean lawngrass 'Zenith'.

Treatment		Soil temperature[z] (℃)					
		Soil depth (mm)					
PS[y]	TD[x] (mm)	Surface		Sub 25		Sub 65	
		Max	Min	Max	Min	Max	Min
Coarse	5	33.3abc[v]	31.1abc	29.6a	28.8a	27.7a	26.7a
	10	37.3a	34.3a	30.7a	29.5a	28.1a	27.3a
Medium	5	32.8bc	30.6abc	29.8a	29.3a	27.6a	27.1a
	10	35.8ab	32.7ab	30.2a	29.3a	27.7a	27.1a
Fine	5	32.0bc	30.1bc	29.7a	28.8a	27.5a	26.8a
	10	34.7ab	31.8ab	30.0a	29.5a	27.8a	27.2a
Control		30.1c	27.9c	29.2a	28.6a	27.2a	26.7a
Statistical significance[w]							
PS		*	*	NS	NS	NS	NS
TD		***	**	NS	NS	NS	NS
PS×TD		NS	NS	NS	NS	NS	NS

[z]Data are the average from Sep. 8 to Sep. 28 in 2001.
[y]Particle size.
[x]topdressing depth.
[w]NS,*,**,*** Non-significant or significant at $P=0.05$, 0.01, 0.001, respectively.
[v]Mean separation within columns by Duncan's multiple range test at 5% level.

추가 주요어 : Zoysia japonica, 내마모성, 배토, 잔디, 토양고결, 토양혼합, 통행, 폐타이어 칩

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