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Research Article
Evaluation of Treading Resistance Using a Modified Treading Load System in Turfgrass

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Abstract
Background and Objective: Turfgrass resistance to heavy traffic and wear damage is one important quality in turfgrass. Since it differs within species, some wear resistance tests have been developed to further differentiate turfgrasses but they are more laborious and require longer time. Therefore, the aim of the study was to build an efficient tread loading system and evaluate its load condition on 3 commercial turfgrass cultivars: *Zoysia matrella* 'Emerald', *Zoysia japonica* 'Meyer', *Cynodon dactylon*×*Cynodon transvaalensis* 'Tifway' and a new *Zoysia matrella* cultivar 'Wakaba'. **Materials and Methods:** A multiple tread loading system was constructed to accommodate 32 grass trays. Treading test was conducted on 4 turfgrass cultivars and the number of erect stems, stolon dry weight and green turf coverage were analyzed. **Results:** The newly registered cultivar 'Wakaba' had the highest number of erect stems and green coverage in both treading and non-treading (control) tests as compared to zoysiagrasses 'Emerald' and 'Meyer', while bermudagrass 'Tifway' least performed in all tests. **Conclusion:** It is concluded that tread loading system is efficient to analyze treading damage for multiple turfgrasses in a short period of time. In addition, the new cultivar *Zoysia matrella* 'Wakaba' has high resistance to treading and utilization of this cultivar is recommended.

Key words: Bermuda grass, green turf coverage, multiple tread loading system, treading resistance, turfgrass, Wakaba, zoysiagrass

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Competing Interest: The authors have declared that no competing interest exists.

Data Availability: All relevant data are within the paper and its supporting information files.

INTRODUCTION

Turfgrasses are grass species that can form turf and are grown as mats for different utilizations. Zoysiagrass species are one of the most common warm-season turfgrass attributing to their aesthetic qualities. These species have been used for centuries in East Asia as ground cover for cultural landscapes and burial mounds and has been commercially propagated in Japan since the 1700s[1]. Moreover, the widespread use of zoysiagrass as turfgrass began in the early 20th century and are grown in lawns, play grounds, athletic fields, eco-industrial parks and buildings and in areas which need protective measures against soil erosion[2]. The present commercial use of the zoysiagrass as turfgrass involves mainly three species: *Zoysia japonica*, *Zoysia matrella* and *Zoysia pacifica*. Zoysiagrasses have different utilizations depending on their respective characteristics. As a result, varieties with various characteristics which are either from selected ecotypes or crossings of zoysiagrasses are grown[3]. Previously, the authors selected a *Z. matrella* ecotype which has fast ground covering, late winter dormancy and early spring green-up and registered it as a new cultivar *Z. matrella* 'Wakaba'[4]. To be able to register a new turfgrass variety under the Plant Variety Protection (PVP) in Japan, it is necessary to investigate 25 characteristics including grass type, to clarify its distinction from other existing varieties. Therefore, in order to expand the utilization of registered varieties, it is important to conduct surveys that assume actual usage situations[3].

Treading resistance is an important research item to assess the effects of treading on the physical damage such as fraying or breakage of stems and leaves, inhibition of root elongation by soil hardening and on the regeneration ability of zoysiagrass. *Zoysia* species have resistance to treading and drought. However, *Z. pacifica* is limited to small-scale use because of its slow growth[5]. Likewise, some cultivars of *Z. matrella* are one of the tread-resistant turfgrass but their low resistance to cold is a limiting factor to their propagation in cooler regions[6,7]. *Zoysia matrella* has an intermediate characteristic of *Z. japonica* and *Z. pacifica* and forms a fine and beautiful turf, so it is frequently used in parks or gardens or as sports turf such as in golf courses. However, the evaluation of such characteristics is not investigated at the time of cultivar registration of 'Wakaba' and it is necessary to investigate treading resistance of this cultivar in order to select its suitability to actual conditions.

Turf treading of children and students affects the green scenery of school grounds planted with *Zoysia* species, therefore, treading resistance tests were previously conducted using stepping roller or pressure roller to determine wear damage[5,8-10]. In particular, Nakamura and Shibuya[10] developed and evaluated the "treading load reproduction system" that overcomes the problems of non-uniformity and labor in various treading processes. However, this system can only accommodate 4 samples which is limiting specially when used in larger fields. Multiple devices or movement of devices are required to evaluate multiple samples including simultaneous repetition.

Therefore, this research innovated the tread pressure load reproduction device developed in the previous report by Nakamura and Shibuya[10] as a part of establishing various practical evaluation methods in zoysiagrass. In this study, we have established a new treading load system and evaluated its load conditions on some commercial turfgrass cultivars.

MATERIALS AND METHODS

Plant materials: Three kinds of zoysiagrass cultivars, *Zoysia matrella* 'Wakaba' and 'Emerald', *Zoysia japonica* 'Meyer' and a hybrid Bermuda grass cultivar 'Tifway' (*Cynodon dactylon* × *Cynodon transvaalensis*)[11] were used in this study. 'Meyer' and 'Emerald' are standard cultivars for the registration test of new zoysiagrass cultivars in Japan. 'Wakaba' is a new breed of zoysiagrass derived from *Z. matrella* registered in the database of the Plant Variety Protection (PVP) System of the Ministry of Agriculture, Forestry and Fisheries (MAFF) in Japan in 2015 and exhibits high ground covering, late winter dormancy and "stay-green" throughout the entire winter season[3].

Cultivation method: Seedlings of the test plants and tests were conducted at Fuji Chemical Co., Ltd. Technical Center in Nakatsugawa City, Gifu Prefecture (35°53'N, 137°48'E). Four turfgrass cultivars were transplanted in trays filled with culture soil in October, 2013. Jiffy trays (Sakata Co., Ltd., 27×27×6 cm) were perforated at 13 spots (5 mm in diameter) at the bottom to facilitate drainage. The bottom of each tray was covered with 500 g (about 1 cm) of bottom soil (pumice stone) and culture soil (soil: vermiculite = 5: 1) and was filled with 60 g m^{-2} fertilizer (N:P:K = 8:8:8) at about 1.0 cm near the bottom of the tray. The stolons were removed from fully-grown sods and washed with running water to prevent seed contamination. Thereafter, they were cut to a length of about 5.0 cm and 10 stolons were planted on each tray. Finally, the top of the tray was filled with culture soil to cover the stolons.

These plant samples were grown outdoors from October-December, 2013 and in a green house from January-May, 2014. Treading test was conducted in July, 2014. During the period of the study, 30 g m^{-2} of chemical fertilizer

(N:P:K = 8:8:8) was added once per each month in February and May-August, 2014. Watering was partially performed using timer-type automatic watering. Next, the height of the seedlings was measured with a Fujisaki-type lawn grass height meter (Daito Techno Green Co., Ltd.) and cut with a lawn electric hair clipper to maintain about 2.0 cm. No application of fungicides, insecticides and aeration were carried out.

Weather data: The meteorological data at the test site (Nakatsugawa City, Gifu Prefecture) in 2014 was obtained from the Japan Meteorological Agency website (http://www.jma.go.jp/jma/indexe.html). The normal year is the average of 10 years from 2005-2014.

Tread pressure loading method and measurement of green turf coverage: The fully grown tray grass was designed to be able to process multiple samples by installing 32 pieces around the tread load system. The average speed of the load and the equipment was performed according to the method of Nakamura and Shibuya[10] and three test zones were repeatedly tested on an average speed of the load. After treading, the samples were photographed using a RAW data format to avoid reflection of direct sunlight with a digital camera (LUMIX GX-1 manufactured by Panasonic) 32 cm from the ground part.

Green turf coverage was developed and trimmed with the high quality RAW development software SILKYPIX (Developer Studio 3.1 SE made by Ichikawa Soft Laboratory Co., Ltd.) to extract the green element and Photoshop 7.0 (Adobe Systems Inc.). The image element RGB (red, green, blue) was calculated by multiplying the difference between green and red and the difference between green and blue: the batch processing was performed to binarize green as white and the other colors as black. It was calculated as a ratio of white. The survey was conducted for 5 months from July-November, 2014.

Investigation of erect stem number and stolon weight: Each test material subjected to treading load treatment for 2 months was collected using a 50 mm diameter hole cutter (manufactured by Per Aid Co.) and the above-ground part and the stolon part were collected separately. In the above-ground part, the number of erect stems collected was measured and calculated as the number of erect stems per unit area. After the stolon was dried at 60°C for 4 h, the dry weight was measured and determined as the stolon weight per unit area.

RESULTS

Weather conditions at the test site: Figure 1 shows the meteorological data at the test site in 2014 (Nakatsugawa City, Gifu Prefecture). The temperature remained lower than the normal year (based on averages for 2005-2014) from July to mid-September 2014, especially in mid-September with 19.3°C, where temperature was lower than that in a normal year. Although the temperature from late September to early November was equal to a normal year, it became lower in mid-November and turned higher in late November. Overall, the temperature during the test period was consistently equal to or lower than the normal year. On the other hand, precipitation was low in late July, mid-September and mid-November, especially 4 mm in late July and extreme dryness was observed. As such, the temperature and precipitation during the experiment period were almost equal to a normal year, except for lower temperatures recorded in June, July, August, September and November, 2014.

Improvement of tread load system and measurement of green turf coverage: Figure 2a, b show the tread load reproducing devices developed by Nakamura and Shibuya[10]. This device has a specification that reproduces the load on an actual playground and was used as a pressure resistance test with a relatively large area of 3.0 m^2 (2.0×1.5 m). However, this method required fixing the soil and turfgrass at the test area to maintain the evenness of the soil in the field and the evenness of the test species. In addition, the number of samples that can be processed one-time by the current method was limited to 4 samples. The evaluation was sometimes difficult depending on the growth condition of the turfgrass. Therefore, we tried to improve the system where in multiple samples of grass can be evaluated one-time (Fig. 2c, d). In addition, 32 trays with the 4 turfgrass cultivars were placed under the locus of the rubber tire of the treadmill and fixed with bricks. Also, using this improved system, we investigated the green turf coverage among several cultivars under treading conditions.

Figure 3 summarizes the effects of treading treatment on green turf coverage in the 4 turfgrass varieties. The green turf coverage in the untreated area increased in all cultivars from July to August but tended to decrease after October. Furthermore, the reason why the green turf coverage decreased extremely in all cultivars with the untreated area in November was generally considered to be an influence of low temperature and less precipitation. On the other hand, the

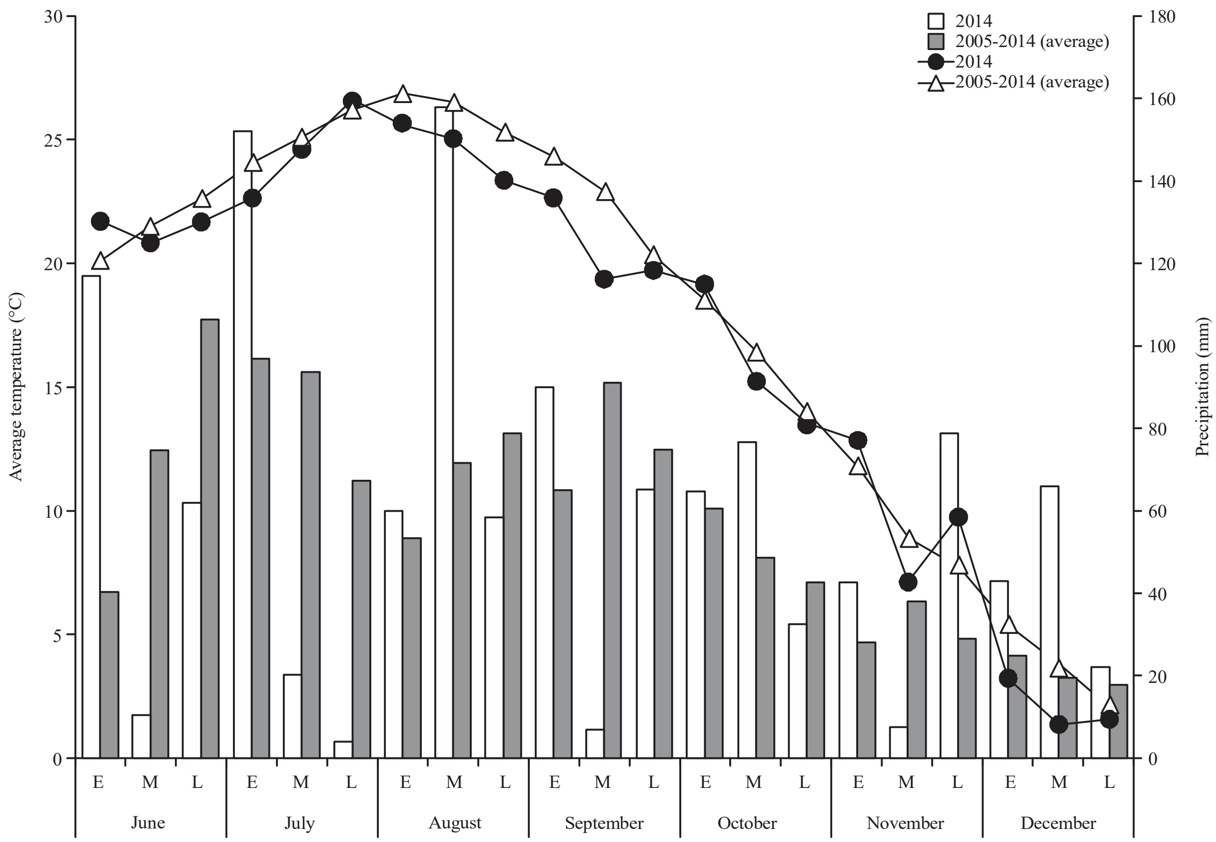

Fig. 1: Meteorological data (average temperature and precipitation) at the test site in Nakatsugawa, Gifu, Japan
E: Early, M: Middle, L: Late

green turf coverage in the treading treatment area of cultivars following treading treatment tended to decline uniformly after having reached the peak in August, with the exception of 'Tifway'. In particular, 'Tifway' had a low green turf coverage value. On November 22nd, all cultivars had <10% green turf coverage as precipitation and temperature were very low in mid-November. The green turf coverage of the 4 non-treated cultivars for treading tended to be high for 'Wakaba' and low for 'Tifway' throughout the experiment period, except in July 2014. However, the green turf coverage of 'Meyer', 'Emerald' and 'Tifway' dropped sharply to 1.25, 17.3 and 3.33% in November, respectively, but that of 'Wakaba' was as high as 59.5%. From this, 'Wakaba' was excellent in maintaining the green turf coverage in winter. On the other hand, the green turf coverage at the treated areas of 4 cultivars was also highest in 'Wakaba' and lowest in 'Tifway' during the period of the study, except in July 2014. 'Wakaba' was the highest in August 21, 2014 in the peak period, exceeding 80%. Overall, 'Tifway' was susceptible to low precipitation and was less green than the zoysiagrass cultivars.

Figure 4 shows the photographs of treated and untreated turfgrass cultivars and their respective images after batch processing in September 19, 2014. The left side shows the untreated area (control), the right side shows the treading area, the upper side shows the original image and the lower side shows a photograph after the batch process (the green part is extracted as white and the other as black). In any of the systems, it was found that the white portion in the batch-processed image was reduced after treading treatment and the covering portion was reduced by treading treatment.

Number of erect stems and the dry weight of stolons under treading load condition: In order to investigate the effect of loading pressure on the condition of the 4 turfgrass cultivars, we investigated the number of erect stems and dry weight of shoots 2 months after the start of the treading treatment. Table 1 summarizes the effects of treading treatment on the number of erect stems and dry weight of shoots in the 4 test cultivars. The average number of erect stems was highest in the untreated areas of 'Wakaba' (459.4), followed by 'Emerald' (221.0) and 'Meyer' (203.2) and the lowest in 'Tifway' (187.3). In addition, the average number of erect stems decreased after treading treatment in all cultivars, with

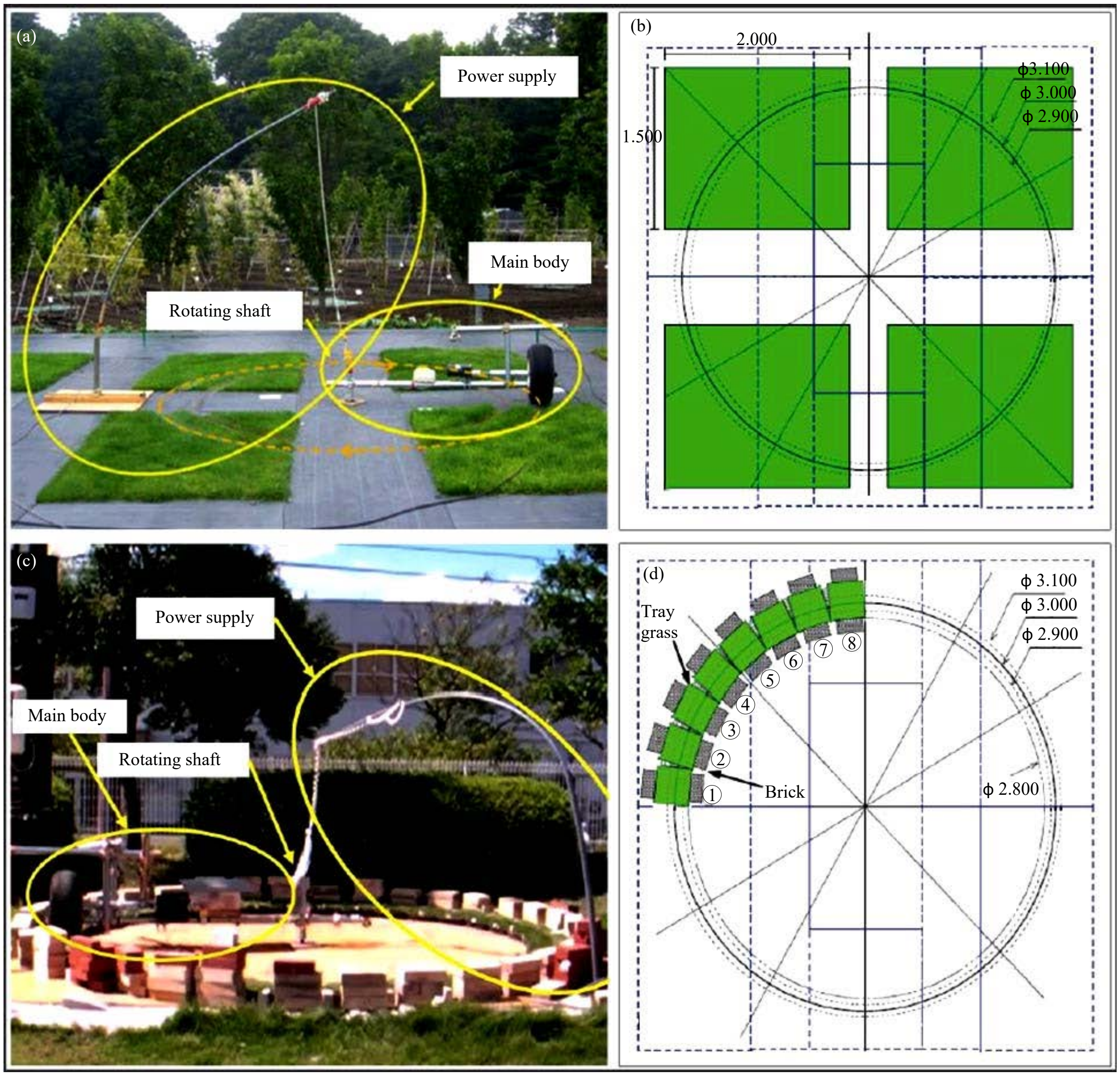

Fig. 2(a-d): (a, b) Comparison of conventional and (c, d) Improved tread load reproduction systems
Both a and b are images adapted from the Research of the turfgrass species for schoolyard lawns in Tokyo by Y. Nakamura and Y. Shibuya, 2012

Table 1: Comparison of the number of erect stems, stolon dry weight and green turf coverage of 4 turfgrass cultivars in September, 2014

	Number of erect stems (100 stem m^{-2})		Stolon dry weight (g m^{-2})		Green turf coverage (%)	
Cultivars	Control	Treading	Control	Treading	Control	Treading
Wakaba	459.4 ± 30.0^{a}	265.9 ± 11.7^{a}	164.0 ± 21.2^{a}	148.5 ± 32.0^{a}	90.25 ± 0.96^{a}	60.56 ± 4.73^{a}
Meyer	203.2 ± 12.5^{b}	166.1 ± 31.3^{a}	126.0 ± 28.3^{a}	169.8 ± 18.3^{a}	77.00 ± 1.83^{b}	50.89 ± 5.66^{b}
Emerald	221.0 ± 92.4^{ab}	184.6 ± 46.0^{a}	184.5 ± 53.0^{ab}	80.5 ± 10.4^{b}	72.25 ± 8.73^{bc}	38.00 ± 6.13^{c}
Tifway	187.3 ± 50.0^{b}	137.8 ± 32.3^{a}	249.0 ± 9.90^{b}	175.5 ± 26.0^{a}	58.75 ± 9.00^{c}	14.17 ± 6.22^{d}

Values are means of replicates, ±indicates standard errors, values within the column followed by the same letters are not significantly different at $p<0.05$ by student's t-test

'Wakaba' having the highest (265.9), followed by 'Emerald' (184.6), 'Meyer' (166.1) and 'Tifway' (137.8) as the lowest. On the other hand, 'Tifway' had the highest value for stolon dry weight among all the untreated (249.0 g) and treated (175.5 g) cultivars. Stolon dry weight in untreated zoysiagrass cultivars decreased in the order of 'Emerald' (184.5 g), 'Wakaba' (164.0 g) and 'Meyer' (126.0 g) while in the treated cultivars, it decreased in the order of 'Meyer' (169.8 g),

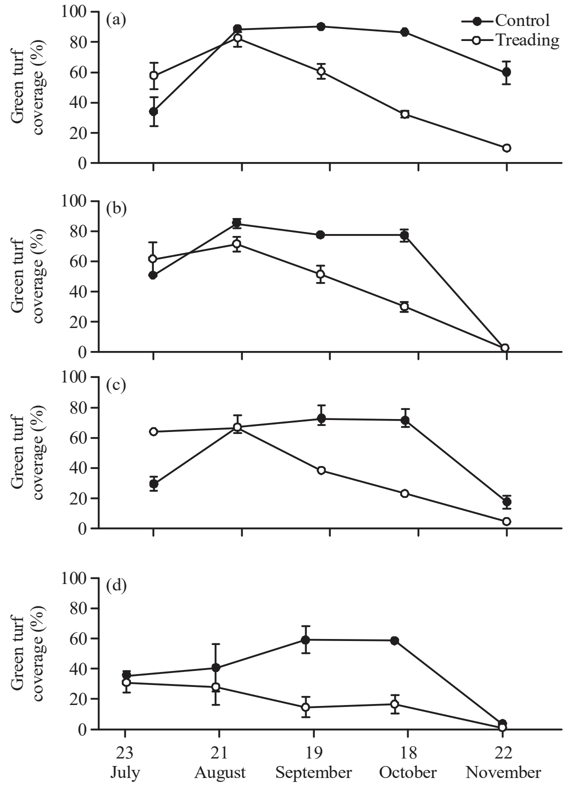

Fig. 3(a-d): Transition of green turf coverage in 4 turfgrass cultivars under treading conditions, (a) Wakaba, (b) Meyer, (c) Emerald and (d) Tifway

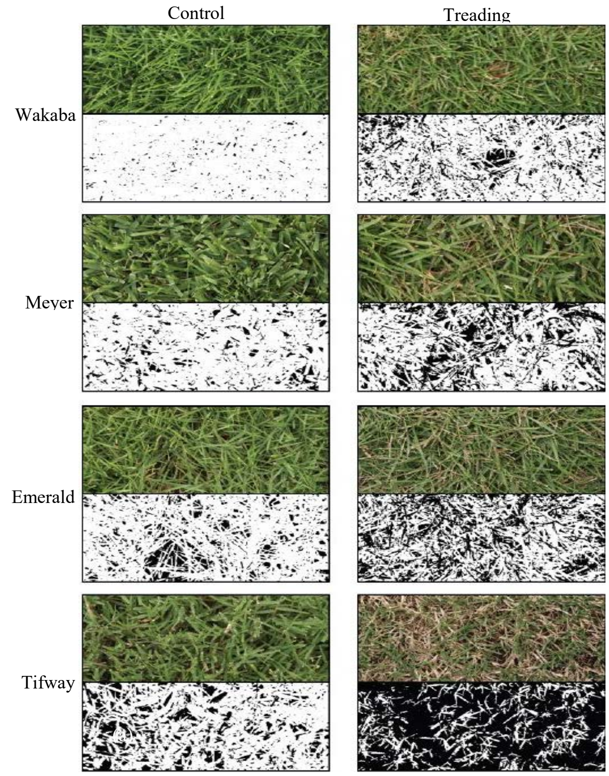

Fig. 4: Effects of treading pressure treatment on green turf coverage in 4 turfgrass cultivars and their batch processing images

Upper: Picture of turfgrass, Bottom: Batch processing image

'Wakaba' (148.5 g) and 'Emerald' (80.5 g). Green turf coverage among untreated cultivars was highest in 'Wakaba' (90.25%), followed by 'Meyer' (77.0%) and 'Emerald' (72.25%), with 'Tifway' (58.75%) as the lowest. For treated cultivars, green turf coverage was significantly different among the 4 cultivars, with the highest percentage in 'Wakaba' (60.56%), followed by 'Meyer' (50.89%) and 'Emerald' (38.0%), while the lowest was in 'Tifway' (14.17%).

DISCUSSION

In this study, the treading resistance of turfgrass was initially evaluated to improve the conventional treading load system for turfgrass[10]. In the conventional foot pressure loading system, it was necessary to move the device to investigate multiple samples. However, our improved system was capable of testing the loading pressure of up to 32 multiple samples without moving the device. In addition, initially, the corners of the tray were set to face the center of the rotation axis but the tray was displaced 45 degrees, so the tray was rotated 45 degrees and the tray was installed parallel to the tire rotation direction (Fig. 2d). When it did, the gap of the tray was canceled. On the other hand, it was impossible to replace the tested zoysiagrass species in the conventional system, so the unevenness or insufficiency of fixing was not tested. However, it was possible to make a reserve for the tray grass and test the zoysiagrass samples with the improved system. Moreover, by rotating the direction of the tray by 180°, processing can be repeated twice with the grass of the same tray and a more accurate tread load test became possible. Furthermore, this improved system can be applied to investigate the influence of differences in soil properties on treading resistance of turfgrass by changing the difference in soil type and nutrient content for each tray.

It has been known that the genus *Zoysia* is generally superior to other turfgrasses in terms of treading resistance because of high fiber and lignin contents of its leaf blades[12-14]. Also, in this experiment, the three zoysiagrass cultivars ('Wakaba', 'Meyer' and 'Emerald') showed higher green turf coverage than Bermuda grass ('Tifway'). Although 'Tifway' was low in green turf coverage, stolon weight was high. Generally, Bermuda grass has been reported to be a treading resistant species with rapid recovery from wear but this was thought to be due to a high stolon weight[6,15].

Based on treading resistance test of zoysiagrass, it was suggested that small turf is less susceptible to treading than large turf and that some gentle treading is better than no treading[1]. Also, in the results of this study, 'Wakaba', had higher green turf coverage than 'Meyer' but both had similar results for treading resistance. The investigation might imply that although there was no correlation between these and green turf coverage in the experiment of Kitamura[1], 'Wakaba' tended to have a large number of erect stems and shoot weight. Because of its similarity to 'Tifway' and 'Meyer', 'Wakaba' is considered to be useful as one of the treading resistant cultivars. However, since the recovery rate after the treading test was not investigated in this study, it is important to conduct a recovery test in the future.

In recent years, genome analysis in three *Zoysia* species was reported. *Zoysia matrella* is highly heterozygous and was reported as an interspecific hybrid between *Z. japonica* and *Z. pacifica*[16]. Kunwanlee *et al.*[17] reported that the trait evaluation of self-pollination in *Z. matrella* showed extremely broad trait segregation in their S_1 hybrids. By utilizing the high heterogeneity of 'Wakaba', we selected S_1 lines (low dormancy) that are more excellent in early spring growth and "stay-green" in winter than 'Wakaba' (parent lines). In the future, we will evaluate the efficiency of the treading load system we innovated in this research to estimate the treading resistance and the selection of inbred lines (S_1) with greater treading resistance than 'Wakaba' (parent).

It is concluded that the improved treading load system of this research is useful for treading resistance test in zoysiagrass and is applicable for the screening of superior lines such as selection testing of treading resistant variety from multiple specimens. In addition, 'Wakaba', which is a cultivar having excellent initial growth, is considered to be usable as a treading resistant cultivar.

SIGNIFICANCE STATEMENT

A multiple tread loading system was constructed to accommodate 32 grass trays. The newly registered cultivar 'Wakaba' had the highest number of erect stems and green coverage in both treading and non-treading (control) tests as compared to zoysiagrasses 'Emerald' and 'Meyer'. Our tread loading system is efficient to analyze treading damage for multiple turfgrasses in a short period of time. In addition, the new cultivar *Z. matrella* 'Wakaba' has high resistance to treading and utilization of this cultivar is recommended.

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