A Report on Putting Green Performance Characteristics

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*I would like to thank all of the golf course superintendents, greenkeepers, course managers, and friends who welcomed me to their golf courses during a busy time and who not only allowed me to collect the data, but provided invaluable support in collecting the data. I would also like to thank Mr. Yukio Ueno for translating this document into Japanese.

Abstract

This report provides a summary of data collected on putting green playability and growing environment characteristics from August 2011 to May 2012. In total, measurements were made on 210 greens[1] on 79 golf courses. Data were collected from eight species of grass growing on putting greens in seven countries. Green speed as measured with the stimpmeter ranged from 173 to 370 cm, with a mean value of 263 cm. Surface hardness measured with a 500 g Clegg impact hammer ranged from 57 to 137 gravities, with a mean of 88.3. Volumetric soil moisture at the 0 to 6 cm depth as measured with a Theta-probe ranged from 4.1 to 62.4% with a mean of 26.7%. Soil temperature at the 5 cm depth ranged from 10.6°C to 33°C with a mean of 24.5°C. Surface temperature of the grass leaves ranged from 8.4°C to 37.8°C with a mean of 25.4°C.

[1] Not all data were collected from all greens. The report provides specifics for each type of measurement.

Contents

1 What data were collected, and why

Why did I collect all this data? What was the purpose? It started with two specific ideas at the start of this past summer. One idea was that I wanted to collect data on the range of temperatures and soil moisture content under which creeping bentgrass is grown in Japan during the summer. I wanted to see how the soil moisture and the temperatures were related to turfgrass quality. The second idea was that I wanted to compare the surface firmness measurements of the Clegg hammer[2] and the Yamanaka tester[3]. Once I began collecting the data, I realized that it would be interesting to also have data on green speed, and that it would be interesting to collect data from a wide range of courses from different geographic regions, with different grass types, and different management practices.

I ended up collecting data at more courses than I had originally planned, because I came to realize that these data are quite interesting for three reasons.

Because it hasn't been done yet The range of values for green speed and surface firmness are not known in exact detail across East and Southeast Asia, yet golfers and turfgrass managers often speak of soft greens or hard greens, fast greens, or slow greens. I wanted to start to put a dataset together that will include these data for a range of courses and grass types in Asia.

Benchmarking Many individual golf courses are interested in how their surfaces are compared with other golf courses around the region or around the world. By collecting and sharing this information, turfgrass managers will have better information.

Better grass and better playing conditions Turfgrass managers can use this information to adjust maintenance practices to reduce stress on the grass, making for healthier plants, and also to ensure that playing surfaces are at or above the desired standard.

If turfgrass managers know what the conditions are, and what work has been done to get the playing surfaces to a certain level, they then are in a better position to adjust or maintain the playing surfaces, and are able to either reduce stress on the turf, or to adjust the playing surfaces more towards the desired condition. With these data, we move toward a situation where maintenance work can be at its highest level of efficiency.

[2] Clegg Impact Soil Tester, SD Instrumentation, http://sdinst.com/

[3] Yamanaka soil hardness tester, Fujiwara Seisakusho, Ltd.

Grass type	Species Name	Percent (%)
Creeping bentgrass	*Agrostis stolonifera*	40
Bermudagrass	*Cynodon dactylon* & *Cynodon* hybrids	23
Seashore paspalum	*Paspalum vaginatum*	16
Korai	*Zoysia matrella* & *Z. pacifica*	12
Annual bluegrass	*Poa annua*	3
Bent-poa	*A. stolonifera* + *P. annua*	3
Fine fescue	*Festuca rubra*	2
Serangoon grass	*Digitaria didactyla*	1

Table 1: Percentage of measurements taken from different grass types for stimpmeter, Clegg Hammer, and temperature data

2 Grass types

A large number of measurements were collected from creeping bentgrass greens at Japan. Table 1 shows the percentage of measurements collected from various species of grass.

"Korai" greens are usually *Z. matrella* at Japan and are *Z. matrella* or *Z. pacifica* in Southeast Asia. "Bent-poa" greens are a mixture of creeping bentgrass and annual bluegrass on the same greens, and "serangoon" grass is also called "blue couch."

3 Data collected

Data presented in this report were collected from the following areas in Japan: Hokkaido, Ibaraki, Tochigi, Saitama, Chiba, Kanagawa, Shizuoka, Yamanashi, Osaka, Hyogo, Wakayama, Hiroshima, Shimane, and Okinawa. Data were also collected at India, Philippines, Sri Lanka, Thailand, Vietnam, and in the United States at California and Oregon.

Green speed was measured using a USGA stimpmeter. As a general rule, three separate measurements of green speed were made on an individual green. Flat areas on greens were chosen for the measurement of speed wherever possible. When flat areas were not available, measurements were made in the uphill and downhill direction, avoiding cross slopes, and the equivalent stimpmeter reading was calculated according to the method described by Brede (1991). Srixon Z-STARxv golf balls were used in the measurement of green speed.

The Brede formula for calculating the corrected green speed on surfaces with a uniform slope less than 6% is

$$S = \frac{2ab}{a+b} \quad (1)$$

where,
S = ball roll distance (corrected green speed)
a = ball roll distance uphill
b = ball roll distance downhill

Note that equation (1) is not the same as the standard equation (2) for calculating ball roll distance which is the arithmetic mean of the uphill and downhill direction, limited to a maximum difference between the two directions of 45 cm:

$$S = \frac{a+b}{2} \quad (2)$$

where,
S = ball roll distance
a = ball roll distance uphill
b = ball roll distance downhill

In practice it is difficult to find flat areas on putting greens with a difference of less than 45 cm in roll, and thus the Brede formula is quite useful. All green speeds in this report, unless otherwise noted, were calculated using equation (1).

Green firmness was measured using a Clegg hammer from SDi with a 500 g domed end probe (golf probe). Nine readings were taken from each green, with one reading being a single drop of the hammer through a guide tube from a height of 60 cm. Readings are a measurement of the peak deceleration of the hammer's impact with the surface and are given in units of gravities, represented in this report as Gmax. Whenever possible, readings at the same location on the green were also made with a Yamanaka soil hardness tester, and those results are in mm and correspond to a force in kg cm^{-2}.

Soil moisture to a depth of 6 cm was measured with a Theta-probe from Delta-T Devices[4]. Nine readings were made per green, generally in a location close to the Clegg hammer readings.

Soil temperatures were measured at three locations on each green with

[4]Theta-probe, Delta-T Devices, http://www.delta-t.co.uk/

a digital thermometer[5] inserted to a 6 cm depth. Surface temperatures were measured with an infrared thermometer[6], held at approximately 50 cm above the green surface to measure the integrated temperature of a circle on the green surface approximately 5 cm in diameter.

Data were analyzed using R software (R Development Core Team, 2012), graphs were generated by the ggplot2 package (Wickham, 2009), and the English version of this report was generated by the knitr package (Xie, 2012) with final typesetting done in XeLaTeX.

4 Green speed

Figure 1 shows all the measurements of green speed. Of the 623 measurements, there was a range from 173 to 370 cm, with a mean value of 263 cm. Table 2 shows the equivalent speed in feet and inches for the range of green speeds discussed in this report.

The boxplots in Figure 1 show the distribution of the data collected for each grass type. The horizontal line at the center of the boxplot for each species is the median green speed for that grass species. Each individual point represents one measurement of green speed, with its value on the x-axis corresponding to the species of grass, and the value on the y-axis showing the green speed calculated through equation (1) for that measurement.

Data for creeping bentgrass, bermudagrass, seashore paspalum, and korai were all collected from eight or more different golf courses. Data for bent-poa, fescue, *Poa annua*, and serangoon grass were all collected from three or fewer golf courses. We can look at the data for the first set of grass species as being somewhat representative of the species. The data for the second set of species, taken from a limited number of sites, may be more representative of the maintenance practices used at the golf courses from which the data were collected, rather than an indication of the normal range for the species.

4.1 The Brede equation

The Brede equation (1) is extremely useful. On most golf course putting greens, it is difficult to find flat areas to make a stimpmeter reading. In this project, I collected green speed data from 210 greens and even in places

[5]Taylor Precision Products model 9842 waterproof digital thermometer, http://www.taylorusa.com/

[6]Fluke 62 mini infrared thermometer, http://www.fluke.com/

Speed (cm)	Speed (feet)
170	5′7″
180	5′11″
190	6′3″
200	6′7″
210	6′11″
220	7′3″
230	7′7″
240	7′10″
250	8′2″
260	8′6″
270	8′10″
280	9′2″
290	9′6″
300	9′10″
310	10′2″
320	10′6″
330	10′10″
340	11′2″
350	11′6″
360	11′10″
370	12′2″

Table 2: Green speed in cm shown with the equivalent in feet

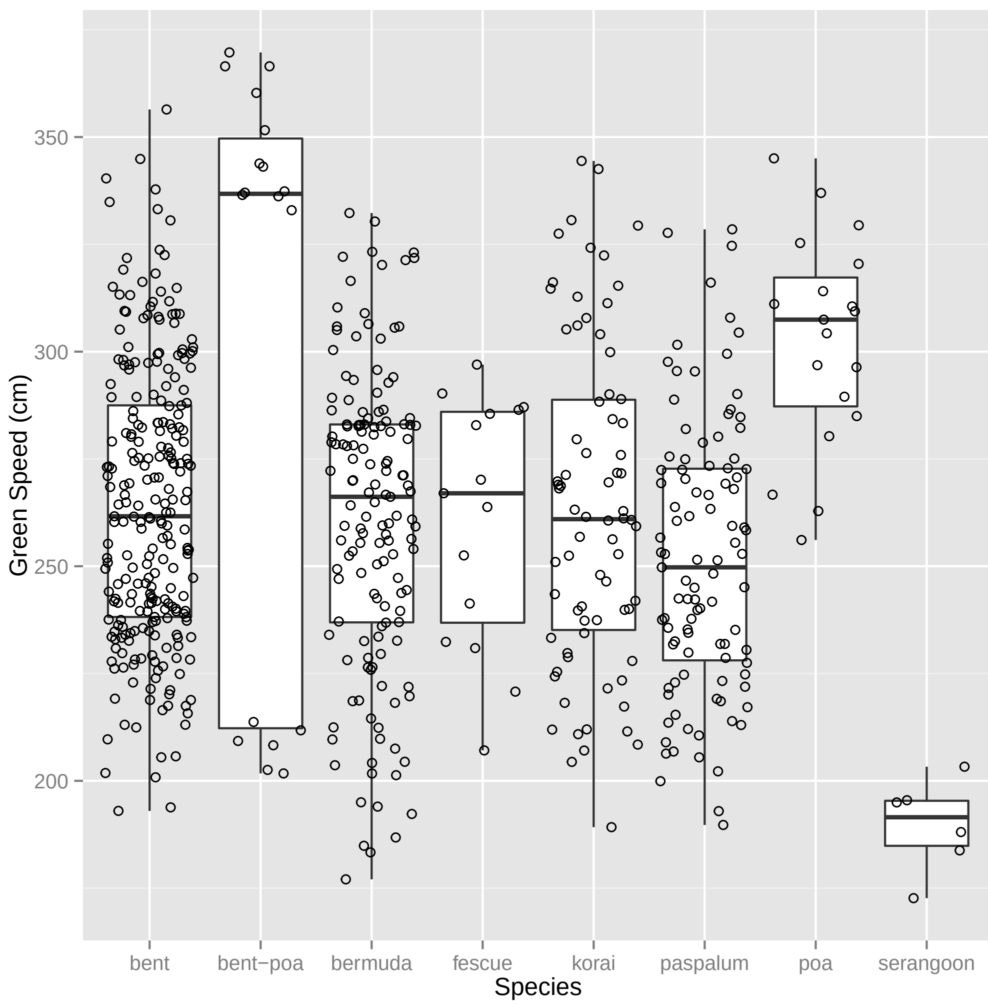


Figure 1: 617 measurements of green speed, separated in boxplots for each species

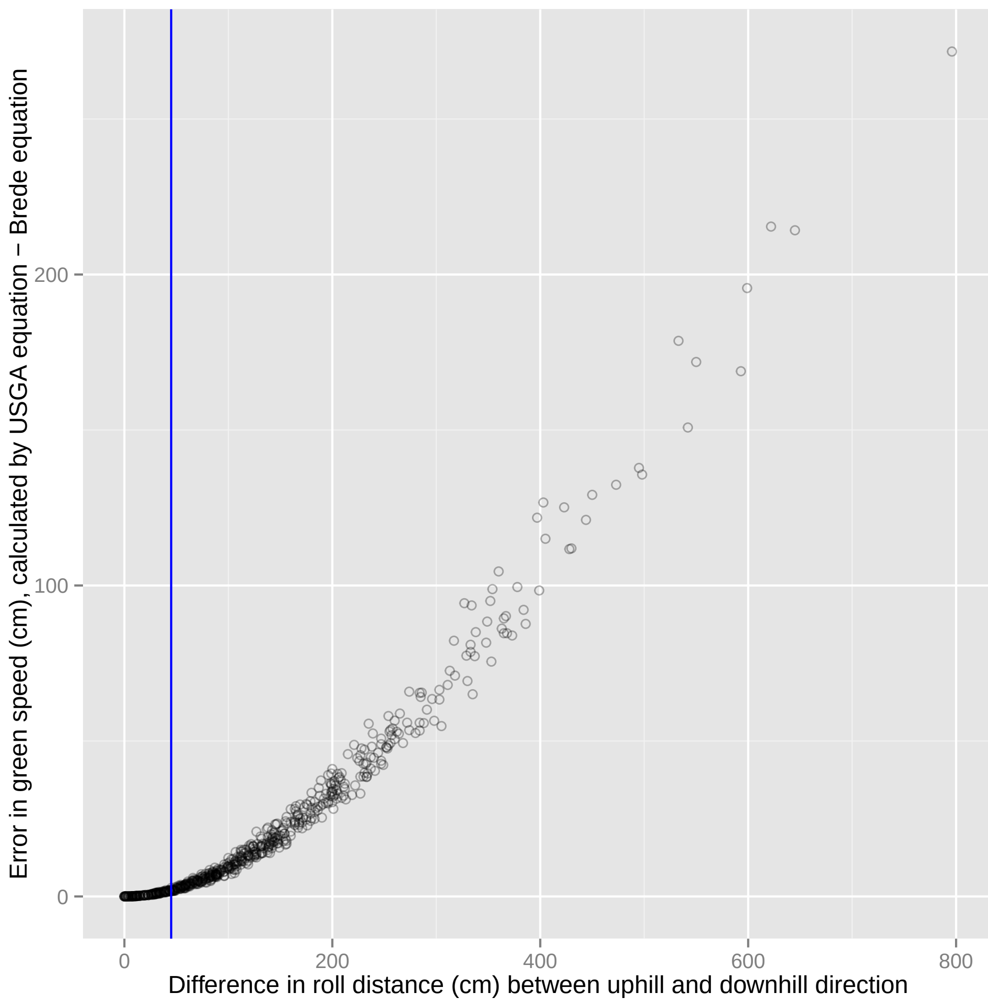


Figure 2: Error in stimpmeter readings increases rapidly when the difference between the two roll directions is more than 45 cm

where the green seemed to be relatively flat, the difference in roll between the uphill and downhill direction was often more than 45 cm. When green speed readings are made, a location at the edge or corner of a green is often selected, not because it is a representative area of the green, but simply because that corner or ridge is flat enough to get a valid reading. Alternatively, slightly sidehill rolls are sometimes made, so that the difference between the two rolls is less than 45 cm, even though the sidehill roll causes a curve that introduces error into the reading.

In Figure 2 we see the error that comes into the stimpmeter reading when measurements are made on a slope such that the difference in roll between the uphill and downhill direction is more than 45 cm. The blue line marks the 45 cm breaking point. With a difference less than 45 cm between the two directions, equation (2) can be used. With any difference greater than 45 cm, the error in the reading is too great, and we cannot make a stimpmeter reading using the standard method.

But wouldn't it be great if we could obtain an accurate stimpmeter measurement on sloped areas where the difference in roll between the uphill and downhill direction is more than 45 cm? Figure 3 shows that we can do that by using the Brede equation (1).

By making multiple measurements of green speed on each green, the data can be organized to compare the green speed within greens. Figure 3 shows that for each of those paired measurements, meaning two measurements taken at different locations on the same green, the speed on the sloped area, even when the difference in roll between the uphill and the downhill direction was 500 cm, once corrected using equation (1), was able to predict accurately the speed measured at a flat (difference between uphill and downhill < 45 cm) location on that same green. In effect, the result of the Brede equation is to remove the error that was shown in Figure 2.

What about that scatter around the 1:1 line in Figure 3? Is that normal, or should we expect that two measurements from the same green should always have exactly the same value? If the stimpmeter reading is identical at the two paired areas, it would be shown in Figure 3 right on top of the blue 1:1 line. What we see in the figure is a little bit of scatter around that line, both for the sloped vs. flat measurements (in orange) and the flat vs. flat measurements (in blue).

Even within one green, it is natural that the speed varies somewhat from point to point. Just because we measure a stimpmeter reading of a certain value at the back of the green, it does not mean that the front of that green, or the middle of that green, will be exactly the same speed. To investigate this in more detail, I compared paired measurements from two flat areas on the same greens (n = 36). I also compared paired measurements

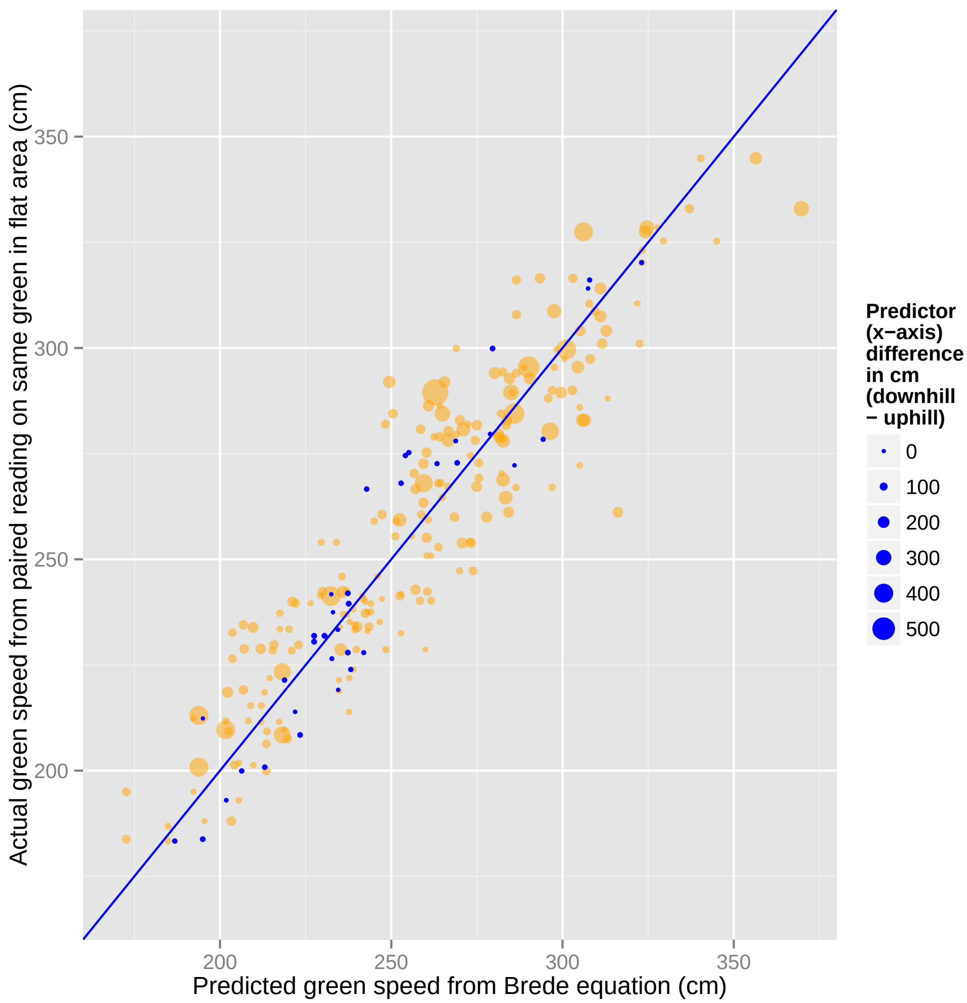


Figure 3: 212 paired measurements of green speed shown in orange use the measurement from a sloped area (x-axis value) to predict the green speed from a flat area (roll difference < 45 cm) on the same green; 36 paired measurements of green speed shown in blue use the green speed of a flat area to predict the green speed of another flat area on the same green; the size of the circles on the graph represent the difference in roll distance between the uphill and downhill direction for the predictor green speed on the x-axis

of a sloped area with a flat area on the same green (n = 212).

In the paired measurements of two flat areas on the same green, the median difference between stimpmeter readings was 9. In the paired measurements of a sloped area to a flat area on the same green, the median difference between stimpmeter readings was 9.9. Based on these results, I would expect that on a typical green, the difference in speed from one area to the next may be about 9 cm. And it appears that including measurements from sloped areas only introduces additional variability of about 1 cm.

To put this variability into context, Karcher et al. (2001) demonstrated that golfers are not able to detect a difference in green speed of less than 15 cm. Repeated measurements of green speed on the same research plots found variability among stimpmeter measurements to be less than 15 cm (Richards et al., 2009) with that variability being attributed to factors such as varying wind speed and direction, non-uniform surface conditions, and differences in leaf blade orientation due to grain or mowing patterns.

A look at the probability density functions (Figure 4) for the sloped vs. flat measurements (orange) and for the flat vs. flat measurements (blue) shows a lot of overlap, although the flat vs. flat measurements have fewer differences above 20 cm. For practical purposes, the distribution of the differences between the paired stimpmeter readings are similar, suggesting that use of the Brede equation (1) on sloped areas of a green produces a stimpmeter reading that is functionally equivalent to the stimpmeter reading on a flat area of the same green.

5 Green hardness or firmness

The hardness of the putting surface is another important performance characteristic. Baker et al. (1996) used a 500 g Clegg hammer to measure the surface hardness of 148 greens on 74 golf courses in Great Britain. Their measurements of Gmax mostly fell within the range of 70 to 150; on greens less than five years old the mean Gmax was 126, with that value decreasing to 108 for courses ten or more years old. Figure 5 shows a histogram of the 2029 measurements I made of Gmax. The most frequent measurements were from 80 to 90, and the range was from 57 to 137 with a mean of 88 gravities.

Figure 6 shows a boxplot of all the Gmax measurements, separated by species. We notice that the warm-season grasses tend to have harder surfaces than do the cool-season grasses, although there is a wide range for all species at which data were collected at more than one course. Data for

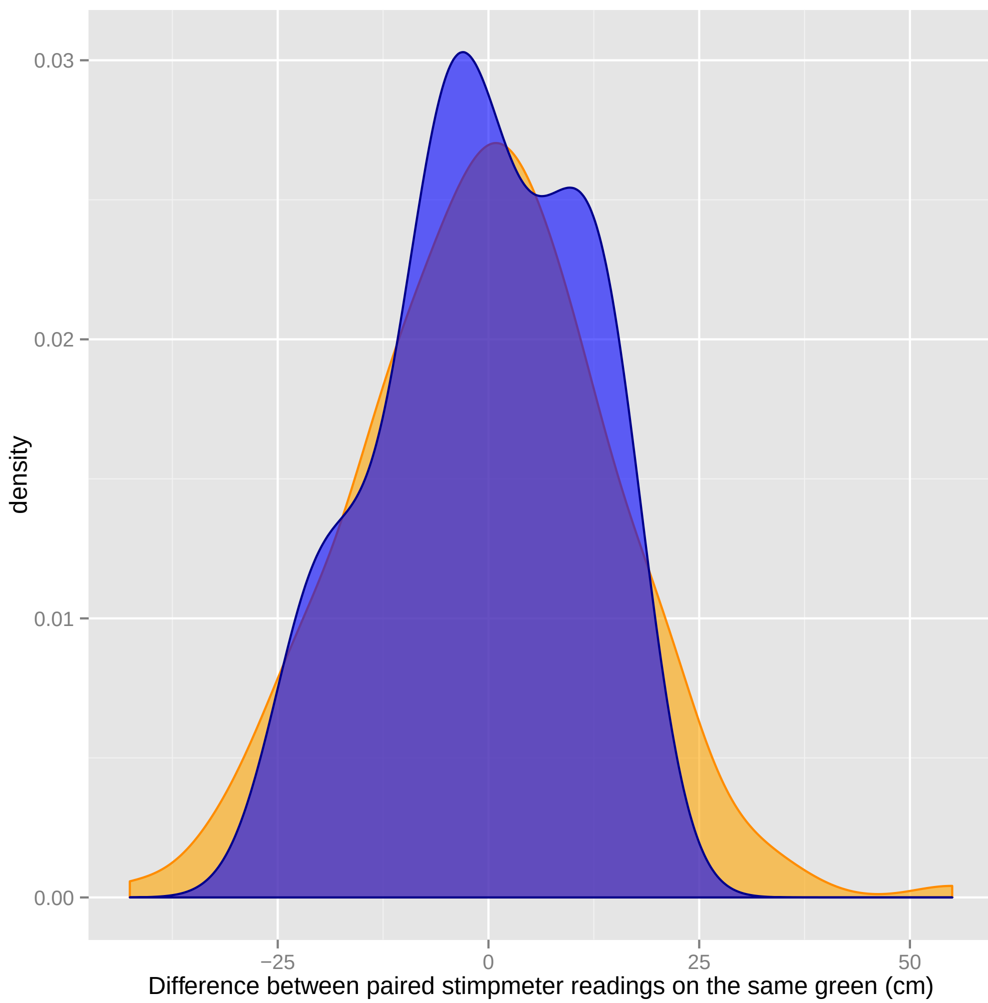


Figure 4: In orange, the probability density function for the difference in 212 paired measurements of Brede equation measurements from sloped areas and a measurement from a flat area on the same green; in blue, the probability density function for the difference in 36 paired measurements of stimpmeter readings from two flat areas on the same green

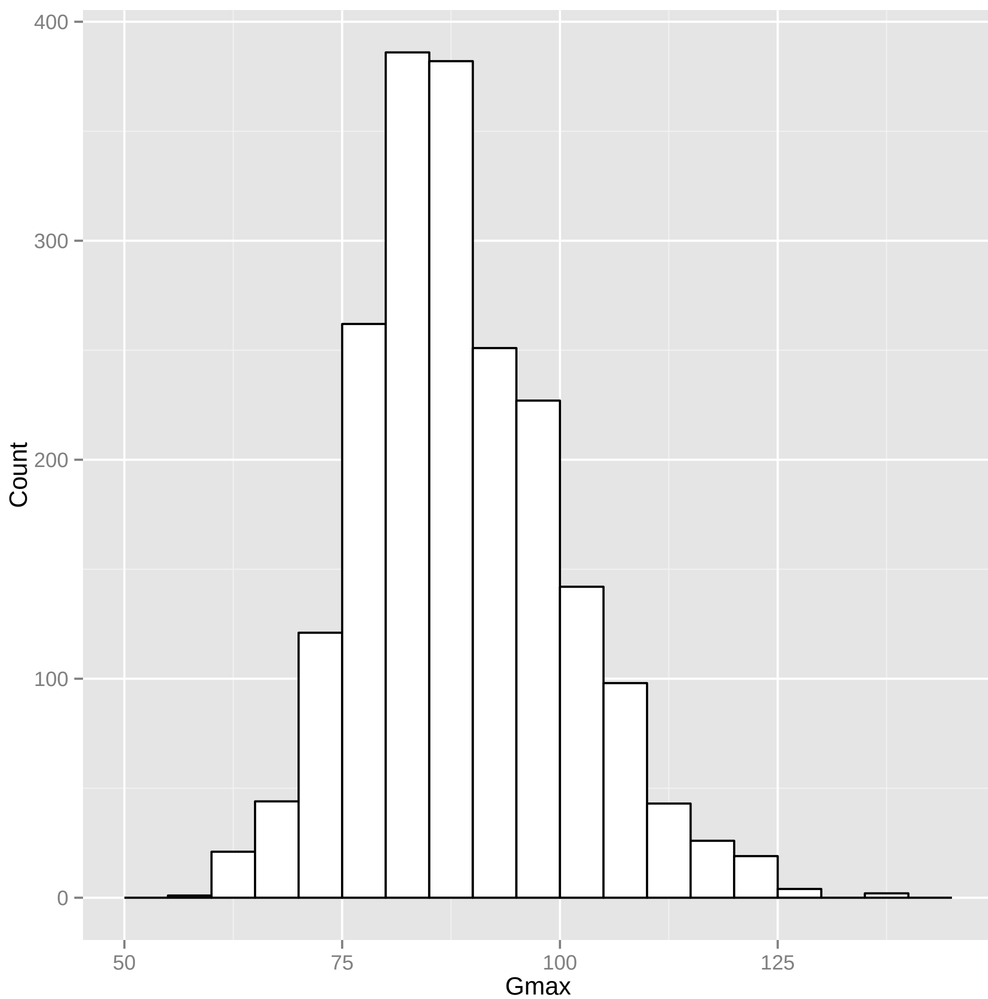


Figure 5: Histogram of 2029 Clegg hammer measurements of hardness (Gmax) on putting greens

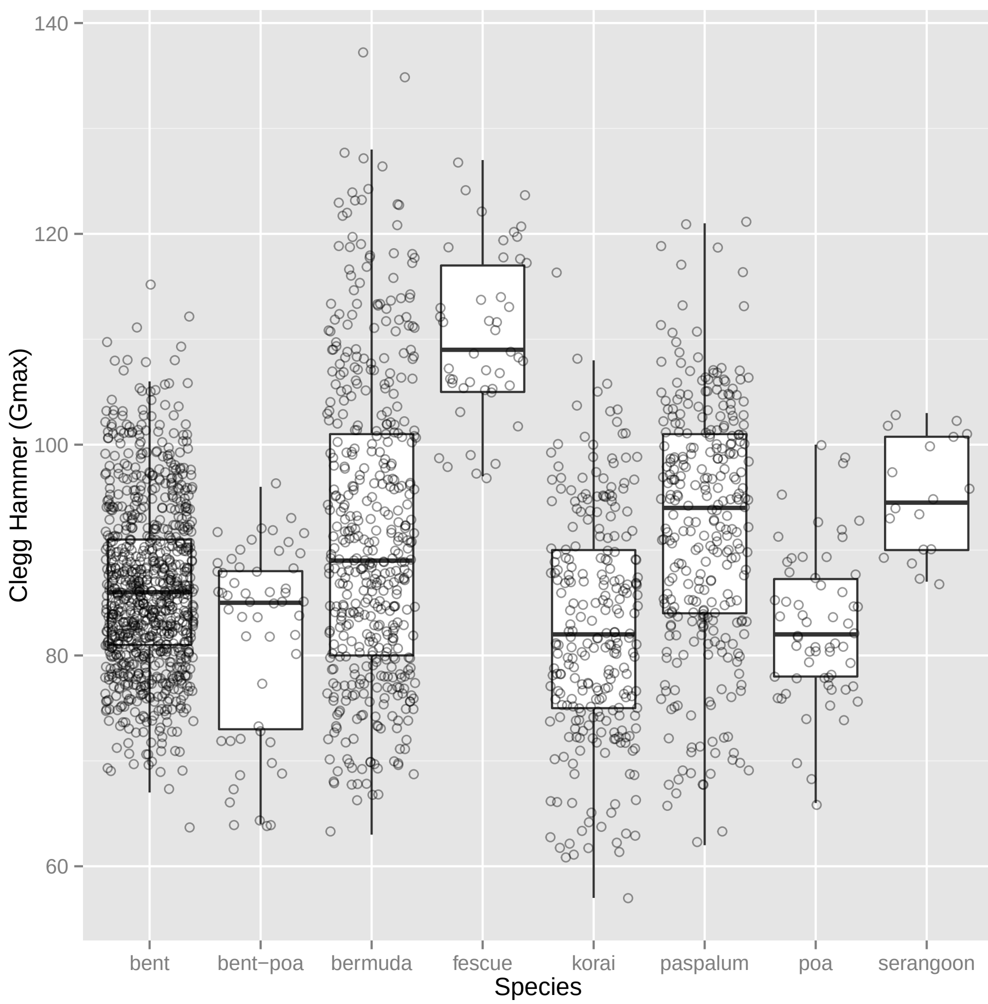


Figure 6: Clegg hammer measurements of green hardness (Gmax), separated in boxplots for each species

bent-poa, fescue, poa, and serangoon grass should be evaluated with care in comparing to other species because those data were collected from a small set of courses, thus the data may represent more about the management of the turf at those courses than about the grass species itself.

I find it interesting that seashore paspalum greens tended to be firmer than did bermudagrass greens. This is probably because seashore paspalum greens tend to be newer, thus probably having less organic matter in the soil, and consequently would be firmer. The korai greens tended to be softer, and I suspect this is for three reasons:

1. Korai greens tend to be older than bermuda or seashore paspalum greens, thus having more organic matter in the soil

2. Korai is a particularly well-adapted grass to East and Southeast Asia where data were collected, so we expect that the grass may naturally produce a large amount of organic matter compared to other grasses in this type of climate

3. It is rare that korai greens receive as much maintenance as do greens planted to another species

We saw in Figure 1 that the speed of korai greens can match the speed of other warm-season grasses; the data in Figure 6 show that korai greens tend to be softer than those of other warm-season grasses. But korai greens tend to receive less maintenance than other grasses. How good can korai greens be, especially in Southeast Asia, with increased frequency of sand topdressing and increased use of growth regulators? Based on these data and the surprisingly high average green speed of korai, the answer may be "surprisingly good".

5.1 Clegg hammer vs. Yamanaka tester

At Japan the Yamanaka soil hardness tester is often used to measure the firmness of a green. One of the objectives of this study was also to evaluate the relationship between the Clegg hammer and the Yamanaka tester.

Figure 7 shows the scatterplot of Clegg and Yamanaka data taken from the same points. This is a rather small dataset, representing 39 greens, 8 courses, and 345 paired measurements, in total. There is more sensitivity to changes in surface hardness when measured with the Clegg hammer than when measured with the Yamanaka tester. The range of measurements in 345 samples was only 9, from a low of 16 to a high of 25, for the Yamanaka

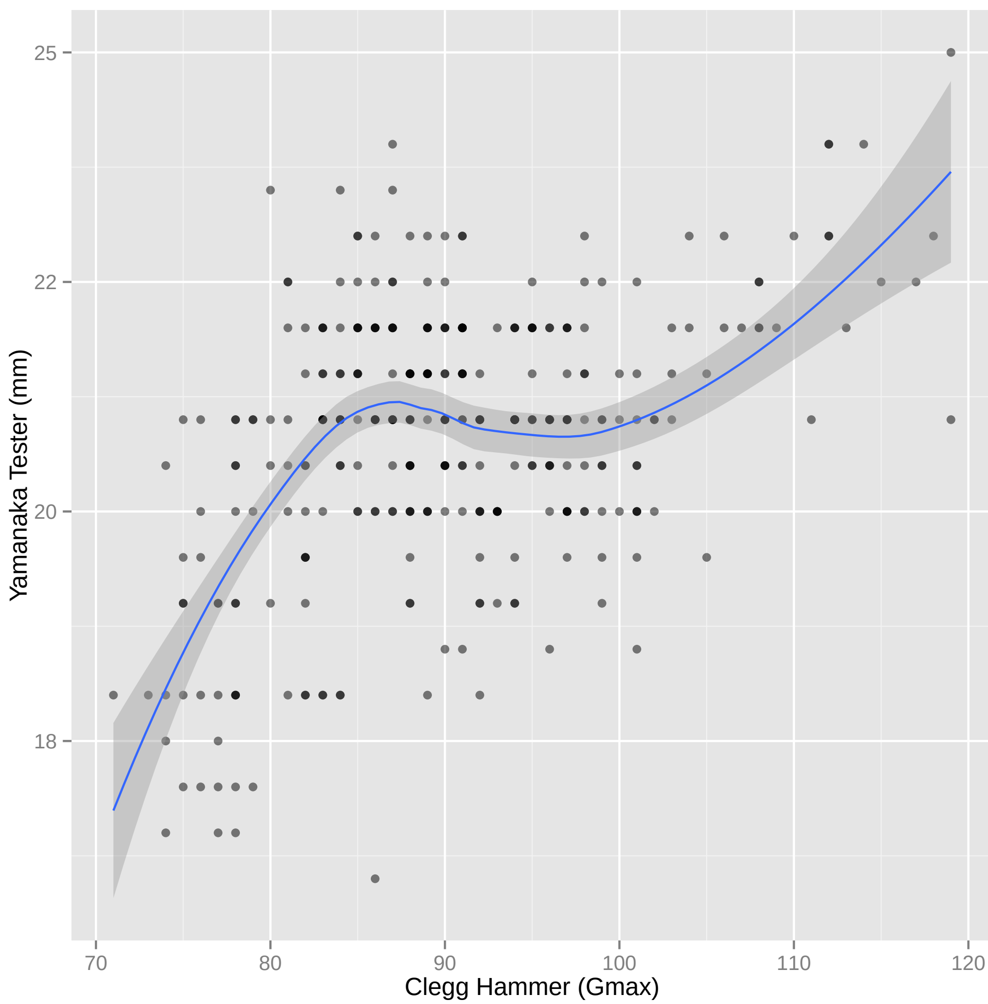
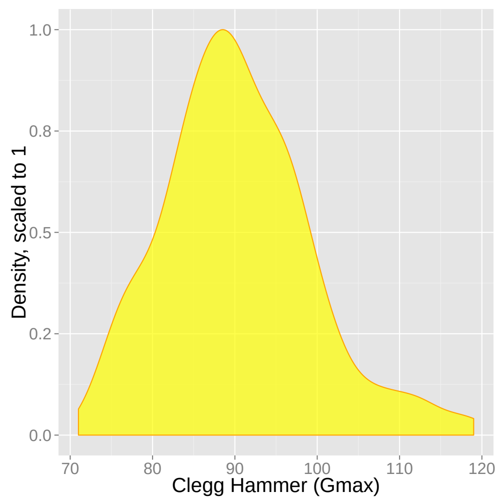
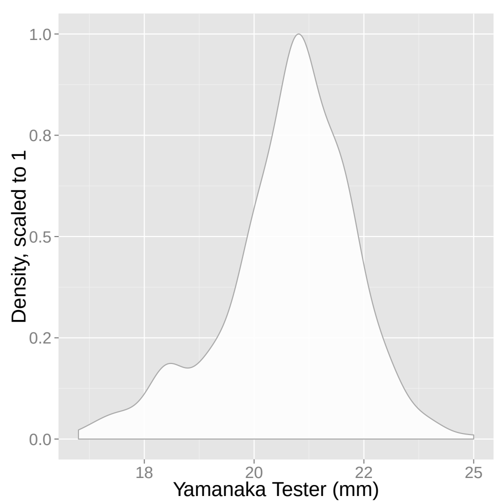


Figure 7: Scatterplot of Clegg hammer and Yamanaka tester, with the blue line showing the mean value of the Yamanaka tester for any value of Gmax

tester. With the Clegg, there was a range of 48 units, from a low of 71 to a high of 119.

We see in Figure 7 that there is a lot of scatter in the middle of the plot. When Gmax is in the range from 80 to 100, which we saw in Figure 5 represents the typical green condition, there is very little correlation between the Clegg hammer reading and the Yamanaka tester reading.





These small plots show a scaled probability density function for the Clegg hammer and Yamanaka tester data. The Clegg hammer at left is in yellow and the Yamanaka tester data is in white at right. The curve for the Clegg hammer data are wider, indicating more sensitivity in the measurements, while the data for the Yamanaka tester are more closely clustered around the values of 20, 21, and 22. For greens that are quite soft, or greens that are quite hard, the Yamanaka tester captures that information. In the middle range of green firmness, however, this limited comparison of the

Clegg hammer and the Yamanaka tester suggests that the Gmax data from a Clegg hammer would be more sensitive to the variability in surface hardness.

6 Soil moisture

There were 1193 measurements of soil moisture, representing most but not all of the grasses tested. Figure 8 summarizes the soil moisture content in a boxplot by species. We note that bermuda and korai had the lowest average soil moisture content, which is what we would expect; warm season grasses use water more efficiently than do cool season grasses and thus can be maintained at lower levels of soil moisture. It is interesting to note that the mean of all the 1193 soil moisture measurements was 26.7%. These data were collected, overwhelmingly, from sand-based USGA rootzones. The USGA recommendations for putting green construction (United States Golf Association Green Section Staff, 2004) specify a capillary porosity at construction of 15 to 25%. On average, the greens that I tested were at or above that level.

There is some indication that soil moisture content has an influence on surface hardness. Figure 9 shows that there are hard greens associated with low moisture content and soft greens associated with soil moisture content higher than 35%. Above 35% soil moisture, turfgrass managers may lose the ability to keep surfaces at a firm level of 100 (Gmax) or above.

7 Soil and surface temperatures

Figure 10 summarizes the temperatures by country, with surface temperatures measured at the time I collected the data shown as green circles, and the soil temperatures at the time I collected data shown as orange triangles. There are obviously a lot of seasonal variations in these temperatures, at least in temperate countries. At Thailand the temperatures near sea level are relatively consistent throughout the year.

It is interesting to note that in Japan, at the hottest time during the summer, the surface temperatures and soil temperatures equal or exceed the temperatures measured at tropical locations in Thailand, the Philippines, and Sri Lanka.

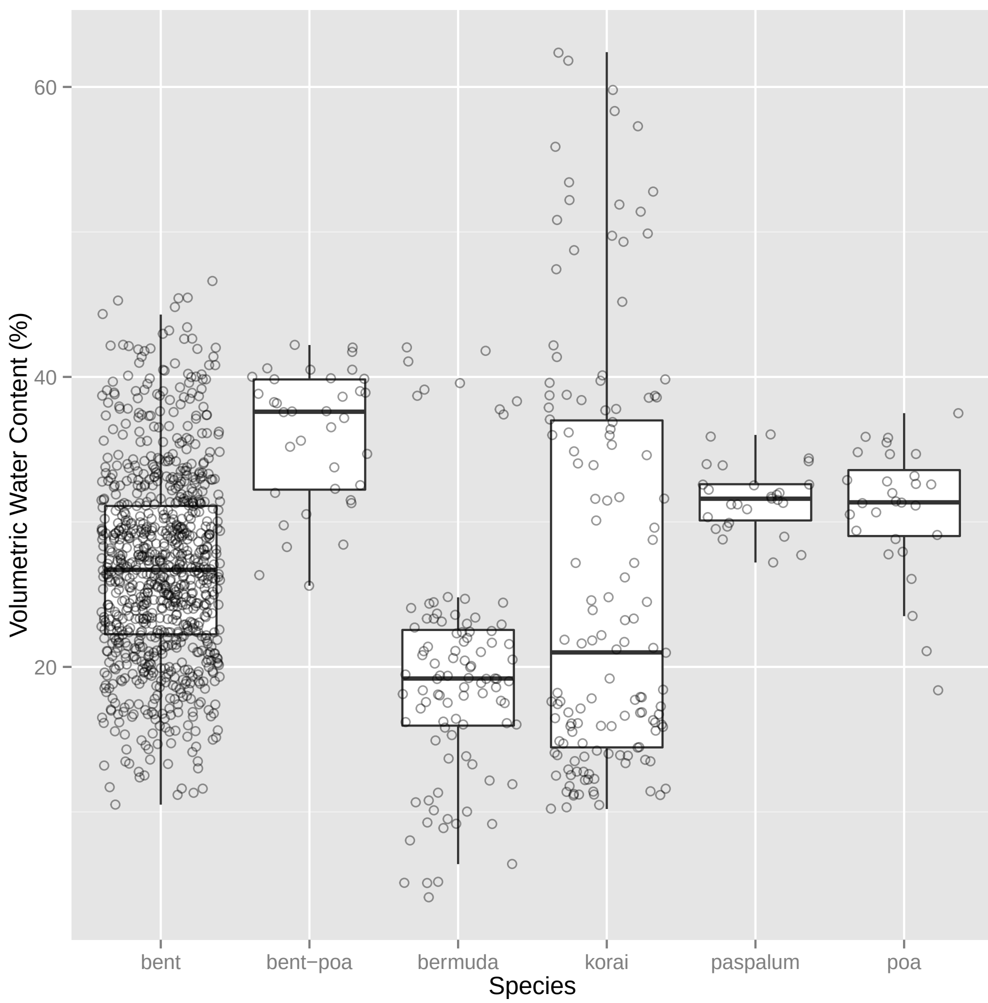


Figure 8: Volumetric soil water content in the top 6 cm of the soil, measured at 1193 points on golf course putting greens, separated in boxplots for each of the six species from which data were collected

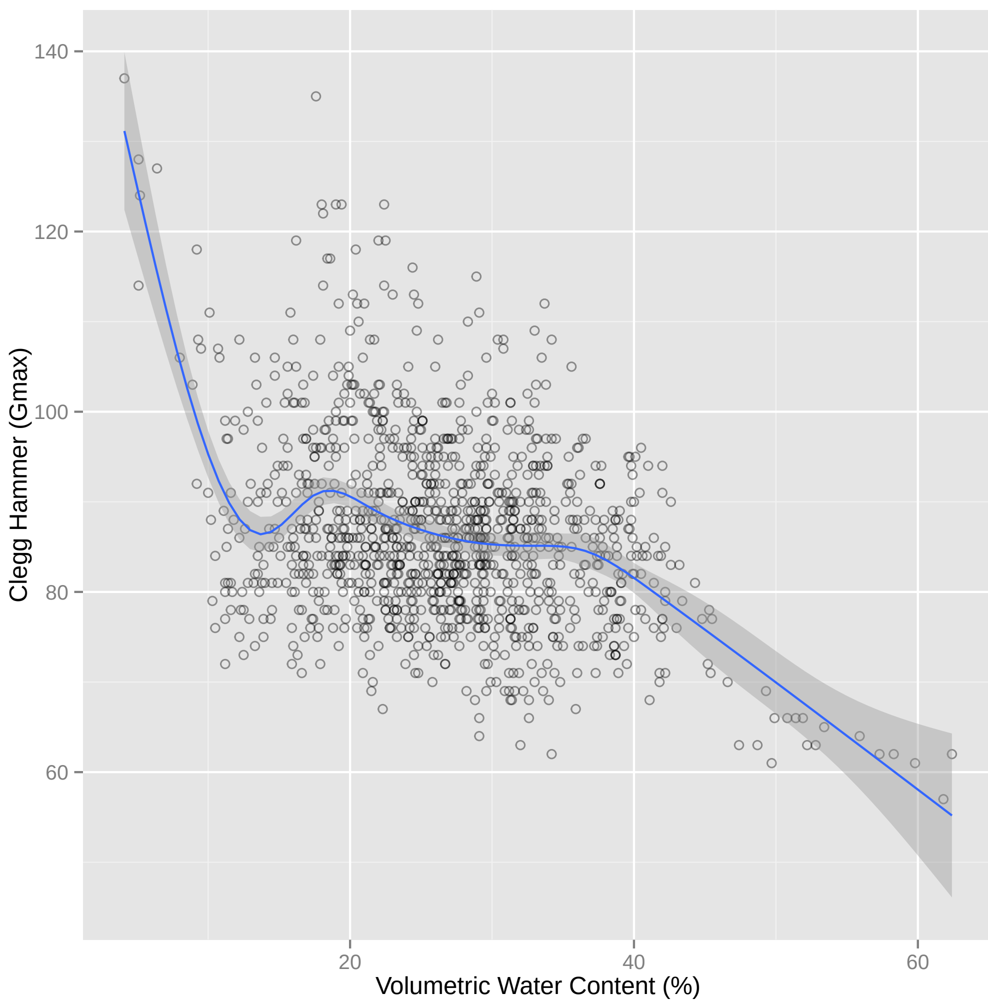


Figure 9: The relationship between soil moisture content measured to a 6 cm depth and surface hardness for 1193 paired samples on golf course putting greens of multiple species

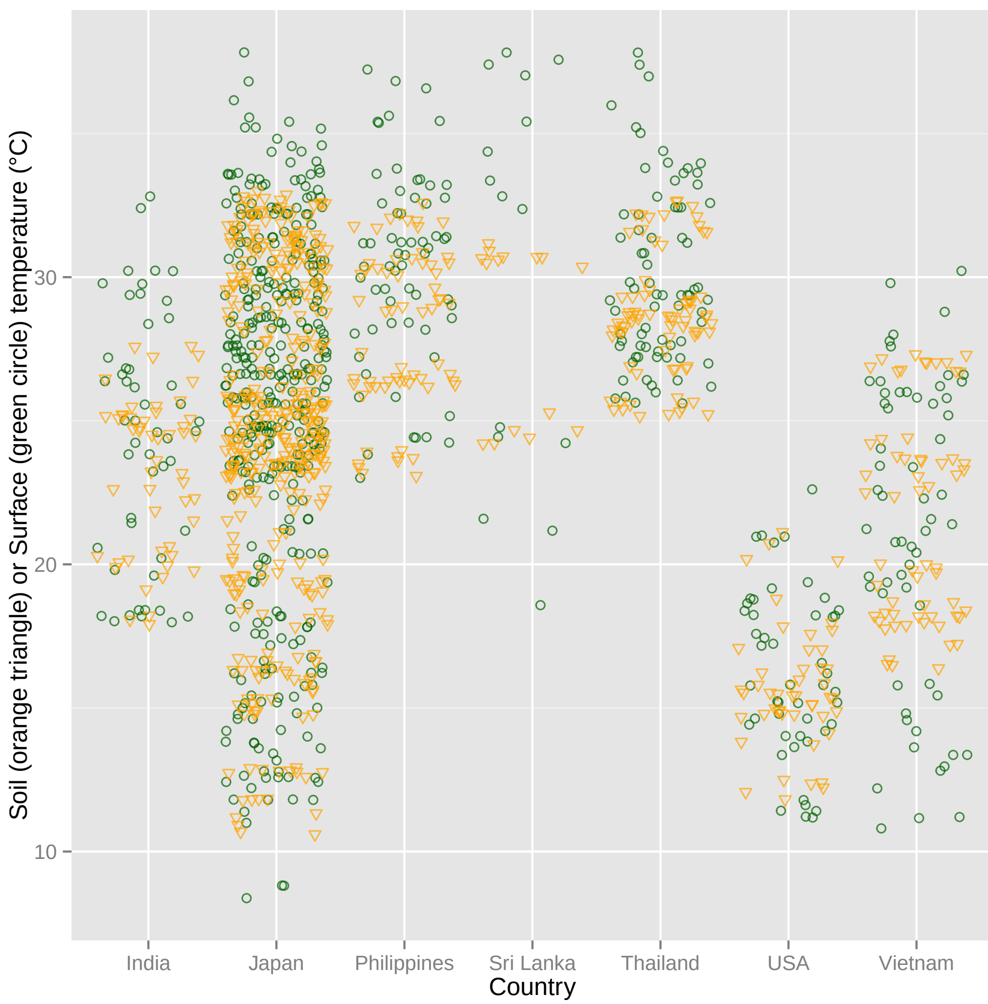


Figure 10: Soil temperature at a 6 cm depth and surface temperature for all the greens from which data were collected

8 Conclusion

The collection of these data and the preparation of this report turned into a much larger and longer project than I had anticipated. This larger project, however, is a more useful one than what I set out to do looking at soil and surface temperatures of some golf course greens in Japan during the summer. For that, I am indebted to the many friends who helped me to collect this data and to the Golf Course Committee of The R&A who provided one of the meters used in this study.

These data, with which I have been wrangling for untold hours, have certainly helped me to learn more about putting green performance and some of the playability characteristics for different grass species and in different countries. I've prepared this report in an attempt to provide a basic summary of the data, to show where the data from your course lie in relation to all the other data I collected, and in a few cases, to show some of the things that I think are really interesting (like the Brede equation!) and to delve into those data in more detail.

I hope you will have found these data as interesting as I have and that this information can be of some use to you in the management of your facility.

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