Penn State's

Center for
Sports Surface Research

Gmax Round-Robin Testing at Penn State Univeristy

September 2013

Contents

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On September 10, 2013, Gmax round-robin testing was conducted at the Joseph E. Valentine Turfgrass Research Center located at Penn State University. This report summarizes the data collected by all testing agencies and applies statistical analyses where appropriate.

Seven testing agencies participated in the testing.

F355	**Clegg Impact Tester**	**F1292**
Testing Agency	Testing Agency	Testing Agency
Agency A	Agency D (3 Cleggs)	Agency E
Agency B	Agency E	
Agency C	Agency F	
Agency D	Agency G	
Agency E		

All participants were asked to conduct Gmax tests on the following 15 surfaces (infill depths shown are the mean depths measured by the testers who measured infill depth):

Synthetic Turf	**Natural Turf**	**Test Pads**
Flexsand infill (FieldTurf carpet; infill: 32 mm)	Bermudagrass (sand rootzone)	A
FieldTurf FT101 (infill: 38 mm)	Bermudagrass (soil rootzone)	B
A-Turf (with pad; infill: 26 mm)	Kentucky bluegrass (sand rootzone)	C
AstroTurf (non-infilled)	Kentucky bluegrass (soil rootzone)	D
Sportexe Omnigrass 51 (infill: 38 mm)		
Low infill Plot A (infill: 19 mm)		
Low infill Plot B (infill: 23 mm)		

The FieldTurf FT101, A-Turf, and Sportexe Omnigrass 51 surfaces were installed in 2002 on a gravel base (A-Turf includes a pad, others do not have a pad). The AstroTurf (non-infilled) test plot was also installed in 2002 after multiple years of use in an indoor football practice facility. The AstroTurf contains a pad and was installed on the same gravel base as the synthetic surfaces listed above.

Each plot was subjected to simulated wear using a Brinkman Traffic Simulator from 2003-2009 (192 passes per year).

The low infill plots were constructed specifically for this testing and consisted of 100% rubber infill installed into 1.75" FieldTurf slit-film carpet on top of asphalt. The target infill depth for Low Infill Plot A was 20 mm and the target infill depth for Low Infill Plot B was 24 mm.

The bermudagrass test plots were mowed at 0.5" and the Kentucky bluegrass test plots were mowed at 1.5". The sand rootzone plots consisted of a high-sand growing media typical of sand-based athletic fields. The volumetric water content of the bermudagrass (sand) plots was 25.2% and the volumetric water content of the Kentucky bluegrass (sand) plots was 24.6%. The soil rootzone plots consisted of a silt loam soil with volumetric water contents of 48.6% and 45.1% for bermudagrass and Kentucky bluegrass, respectively.

Testing was conducted during warm, sunny conditions. All surfaces were dry at the time of testing.

F355 Results

All Gmax results from each testing agency are shown in Table 1. Gmax values ranged from 73.5 (bermudagrass soil rootzone) to 209.3 (Low Infill A). The coefficient of variation for each surface is also shown in Table 1. The coefficient of variation is the ratio of the standard deviation to the mean and is a measure of the degree of difference among F355 devices within the same test plot. A higher number indicates greater variation among the devices than a lower number.

Figure 1 is a boxplot of the Gmax data for all testing agencies at each test location. The boxplot shows the variability among measurements at each test location.

Table 1. F355 results for each testing agency on each surface.

	Agency A	Agency B	Agency C	Agency D	Agency E	Coeff. of Variation
	----------Gmax----------					
A-Turf	103.3	91.0	108.7	102.5	107.5	6.8
Astroturf (traditional non-infilled)	112.0	97.3	119.2	113.7	124.0	8.9
FieldTurf FT0S1	112.2	Not Tested	114.3	122.0	122.8	4.6
Flexsand Infill	156.8	133.2	153.8	160.5	167.0	12.8
Low Infill A	186.7	182.7	209.3	193.9	202.2	5.6
Low Infill B	161.2	147.7	175.3	178.5	182.3	8.5
Pad A	91.2	80.0	95.5	90.4	99.7	8.1
Pad B	112.5	106.7	118.2	111.2	115.8	3.9
Pad C	146.7	130.2	151.8	149.5	161.2	7.6
Pad D	74.5	Not Tested	77.0	71.8	Not Tested	3.5
Sportexe Omnigrass 51	100.8	90.8	106.7	101.9	103.8	6.0
Bermudagrass (sand)	87.8	74.0	83.2	85.2	87.0	6.7
Bermudagrass (soil)	73.5	65.2	75.2	74.2	76.8	6.2
Kentucky Bluegrass (sand)	81.0	74.5	85.2	84.5	84.3	5.4
Kentucky Bluegrass (soil)	121.8	87.3	118.3	122.3	118.0	13.0

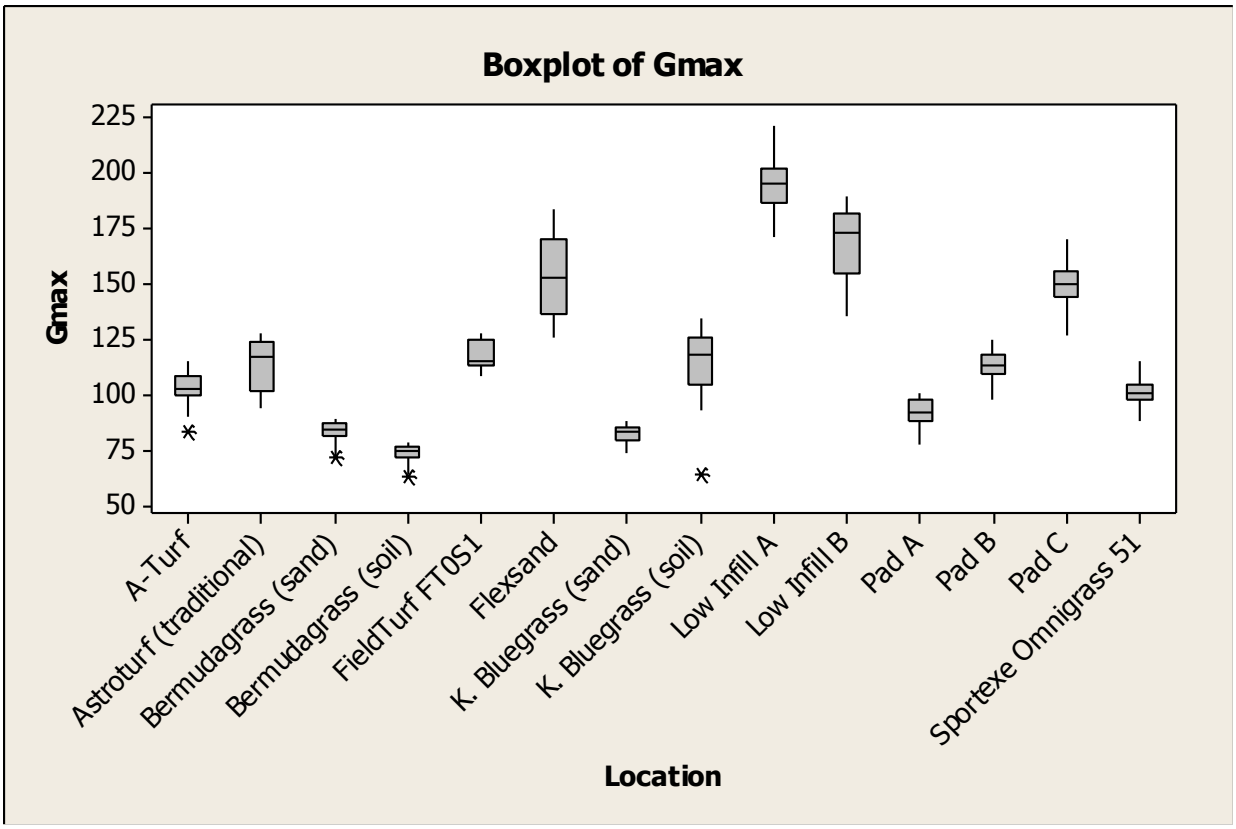

Figure 1. F355 Gmax values for all testing agencies at each test location. The rectangular box represents the middle 50% of the data. The median is represented by the horizontal line inside the box. The vertical lines ("whiskers") extending from the box represent the upper and lower 25% of the distribution (excluding outliers). Statistical outliers are indicated by asterisks.

Given that ASTM F1936 requires three consecutive drops in the same location, correlations between each drop were calculated and are shown in Table 2.

Table 2. Pearson correlation coefficients for Gmax drops

Drops	Pearson Correlation	p-value
Drops 1 & 2	0.971	0.000
Drops 1 & 3	0.962	0.000
Drops 2 & 3	0.988	0.000
Drop 1 & 2 and 3 average	0.969	0.000
Drop 2 & 2 and 3 average	0.997	0.000

Regression analysis was conducted to determine how well the first drop predicts the average of the second and third drop (reported Gmax value). The results are shown in Figure 2. The results show that the first drop strongly predicts the average of the second and third drop.

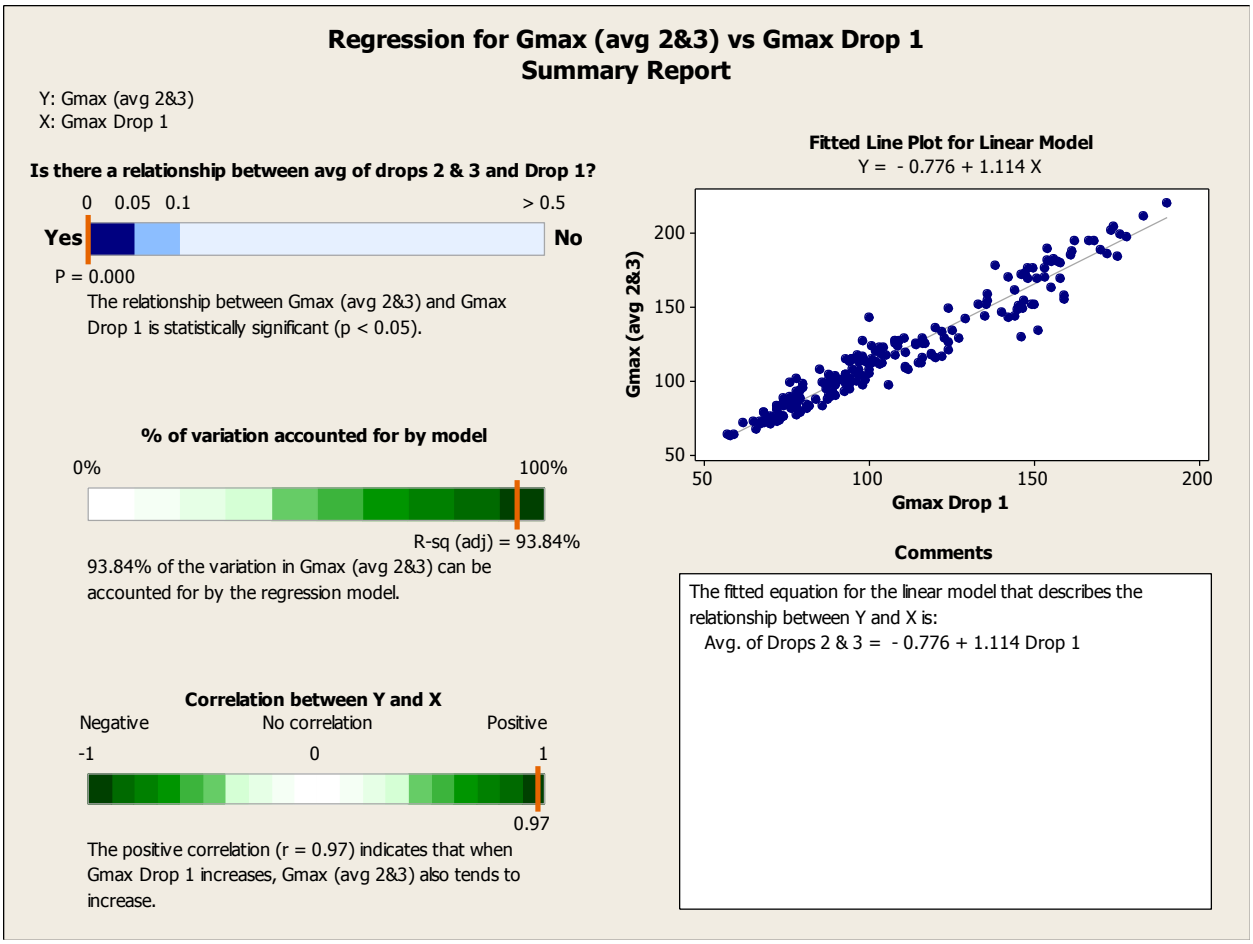

Figure 2. Summary of regression test for the first drop and the average of the second and third drops.

Clegg Results

All Gmax results from each testing agency are shown in Table 3. Gmax values ranged from 49.2 (bermudagrass soil rootzone) to 172.8 (Low Infill A). The coefficient of variation for each surface is also shown in Table 3. With both the Agency D "blue" and "yellow" Cleggs removed (neither is NFL calibrated), the coefficients of variation tended to be lower than the coefficients of variation among the F355 devices.

Figure 2 is a boxplot of the Clegg Gmax data for all testing agencies at each test location. The boxplot shows the variability among measurements at each test location.

Table 3. Clegg results for each testing agency on each surface.

	Agency F (NFL calibrated)	Agency E (NFL calibrated)	Agency G (NFL calibrated)	Agency D NFL Clegg (NFL calibrated)	Agency D – Yellow Clegg	Agency D – Blue Clegg	Coeff. Of Variation	Coeff. of Variation - NFL Cleggs
	----------Gmax----------							
A-Turf	78.8	77.2	82.0	76.7	78.8	91.0	6.6	3.0
Astroturf (traditional non-infilled)	81.0	92.5	84.3	86.8	93.3	109.9	11.2	5.6
FieldTurf FT0S1	80.0	87.1	80.7	81.3	82.9	96.7	7.5	4.0
Flexsand Infill	122.8	133.8	126.4	125.3	123.4	137.5	4.7	3.7
Low Infill A	152.5	137.1	160.2	140.0	168.1	172.8	14.6	7.3
Low Infill B	106.5	105.8	107.7	109.4	114.3	134.2	9.6	1.2
Pad A	73.3	75.8	68.0	71.0	64.8	75.5	6.1	4.6
Pad B	70.8	76.6	64.7	72.2	61.3	70.0	7.9	6.9
Pad C	106.0	105.8	100.3	103.9	102.6	110.6	3.4	2.5
Pad D	Not Tested	Not Tested	Not Tested	45.5	39.9	55.0	16.3	n/a
Sportexe Omnigrass 51	65.2	70.6	66.9	65.1	64.6	77.8	7.5	3.8
Bermudagrass (sand)	60.2	60.5	58.6	57.1	56.3	68.7	7.4	2.7
Bermudagrass (soil)	50.7	54.2	52.8	52.4	49.2	61.5	8.1	2.7
Kentucky Bluegrass (sand)	67.2	63.5	64.6	63.3	55.9	62.4	6.0	2.8
Kentucky Bluegrass (soil)	82.0	97.8	84.2	99.7	96.3	110.6	11.1	10.0

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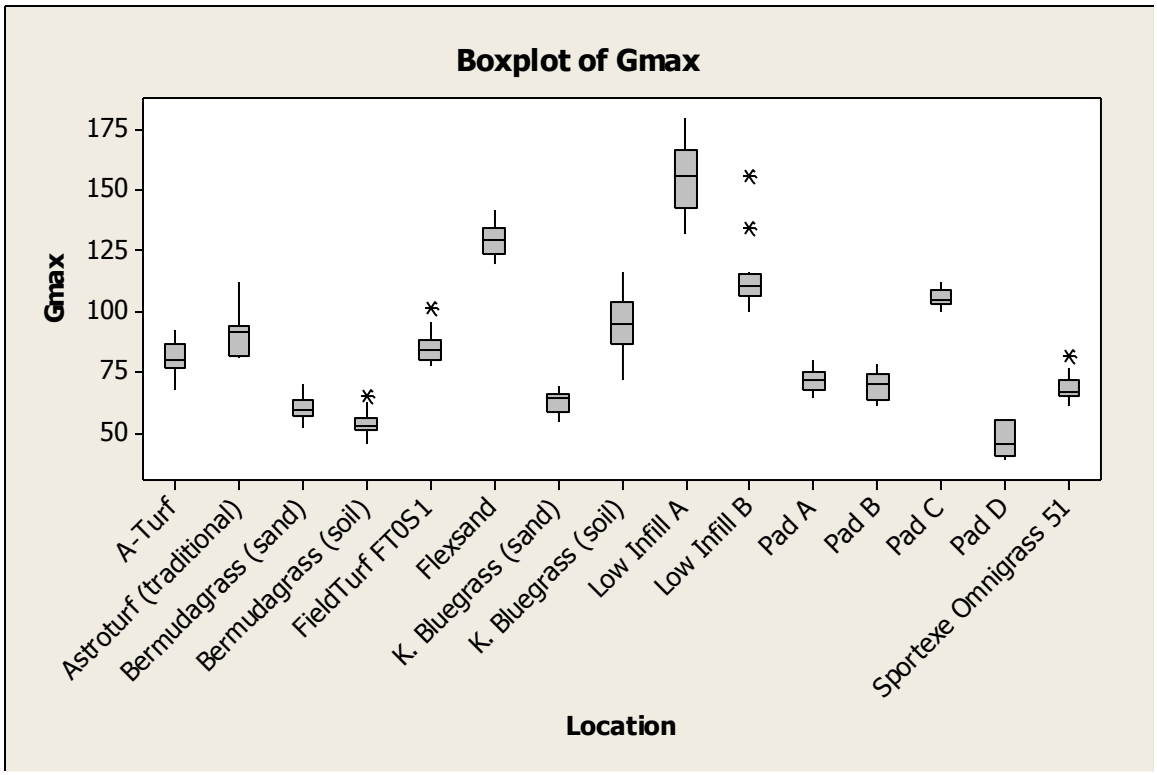

Figure 2. Clegg Gmax values for all testing agencies at each test location. The rectangular box represents the middle 50% of the data. The median is represented by the horizontal line inside the box. The vertical lines ("whiskers") extending from the box represent the upper and lower 25% of the distribution (excluding outliers). Statistical outliers are indicated by asterisks.

F1292 Results

Agency E was the only testing agency to test Gmax with the F1292 device. The Gmax results are shown in Table 4. Gmax ranged from 68.7 (bermudagrass soil rootzone) to 247.7 (Low Infill A).

Table 4. Gmax results for the F1292 device

	Agency E
A-Turf	100.0
Astroturf (1st generation)	123.7
FieldTurf FT0S1	111.2
Flexsand Infill	118.3
Low Infill A	247.7
Low Infill B	196.5
Pad A	76.0
Pad B	86.5
Pad C	132.3
Pad D	Not Tested
Sportexe Omnigrass 51	97.2
Bermudagrass (sand)	78.2
Bermudagrass (soil)	68.7
Kentucky Bluegrass (sand)	76.2
Kentucky Bluegrass (soil)	111.5

F355 – Clegg Comparison

In order to make statistical comparisons and investigate relationships between the two devices, an equal number of F355 devices and Cleggs was required for the most robust testing. This allows for direct comparisons for not only the mean of each device on each test surface, but also each of the three test spots within each location. Therefore, for statistical analysis, the Agency D "blue" Clegg was eliminated in order to get an equal number of F355 devices and Cleggs. The Agency D "blue" Clegg was not calibrated to the NFL standard. Pad D was not included in the analysis as several testing agencies did not test Pad D.

The relationship between the F355 and the Clegg Gmax results is shown in Figure 3. The same data is presented in Figure 4 with each test location identified.

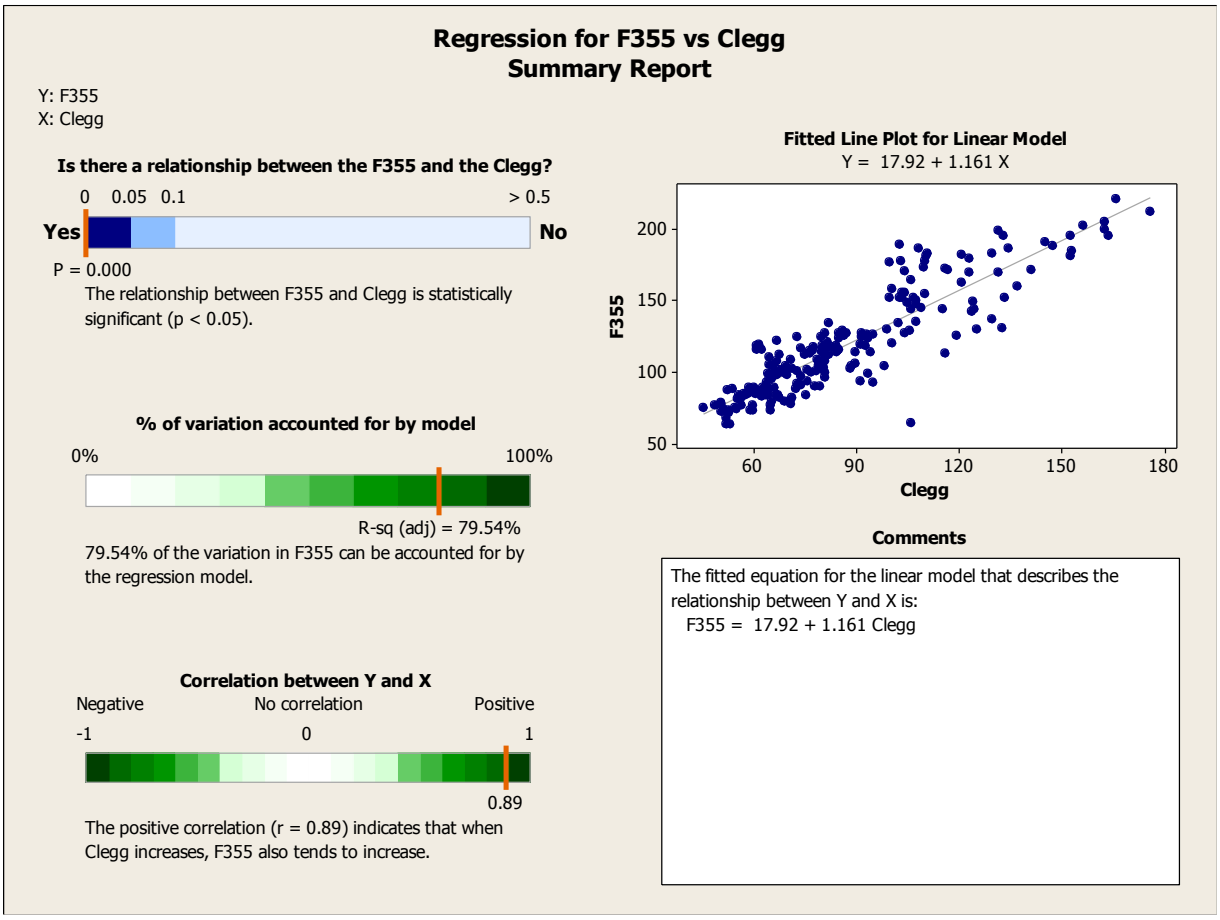

Figure 3. Summary of regression test for the F355 and the Clegg

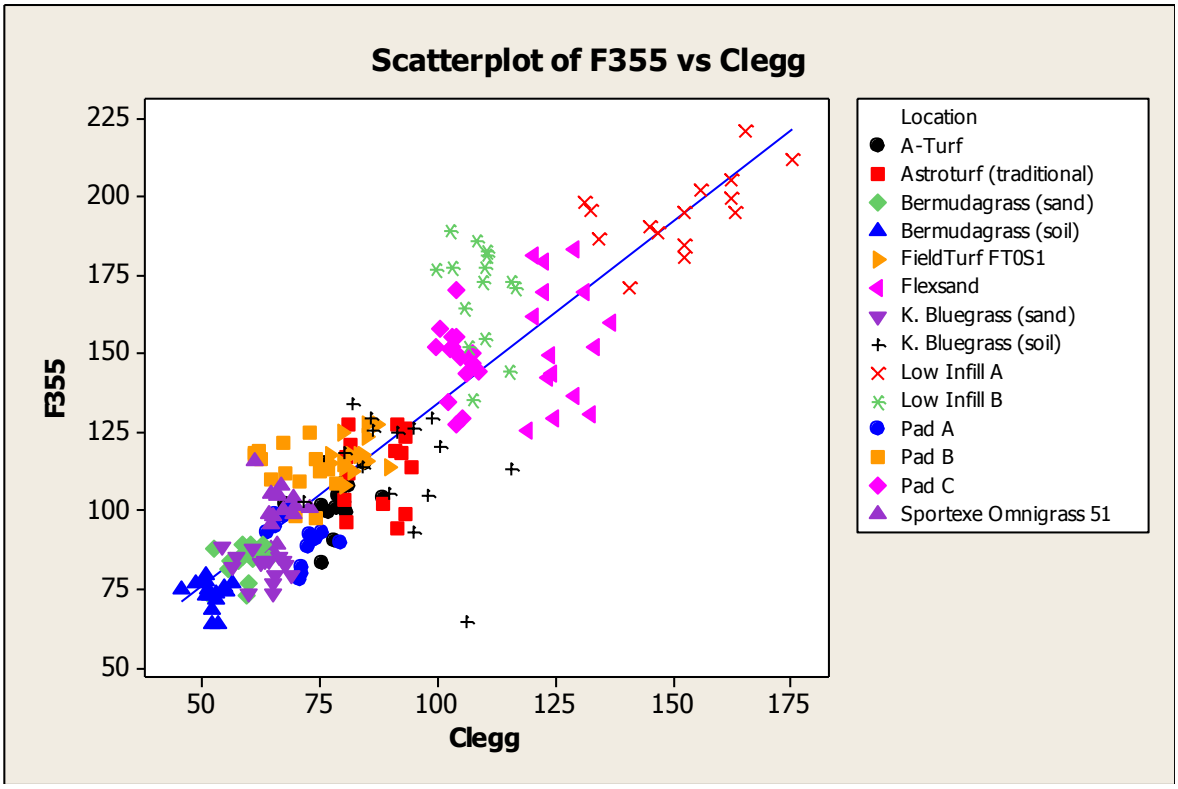

Figure 4. Scatterplot of the relationship between Gmax values obtained with the F355 and Clegg with test locations identified

The Gmax data collected in the round-robin testing shows a strong relationship between the F355 and Clegg. The correlation coefficient is 0.89 and R-squared value from the regression analysis 79.5%. There is no indication that one device is better able to sense a surface with a higher Gmax than the other.

F355 – F1292 Comparison

Because there was only one F1292 device, the mean across all F355 devices was used when comparing the F1292 device to the F355 device. Pad D was not included in the analysis as several testing agencies did not test Pad D. Results of the regression analysis are shown in Figure 5 and each test locations are identified in Figure 6.

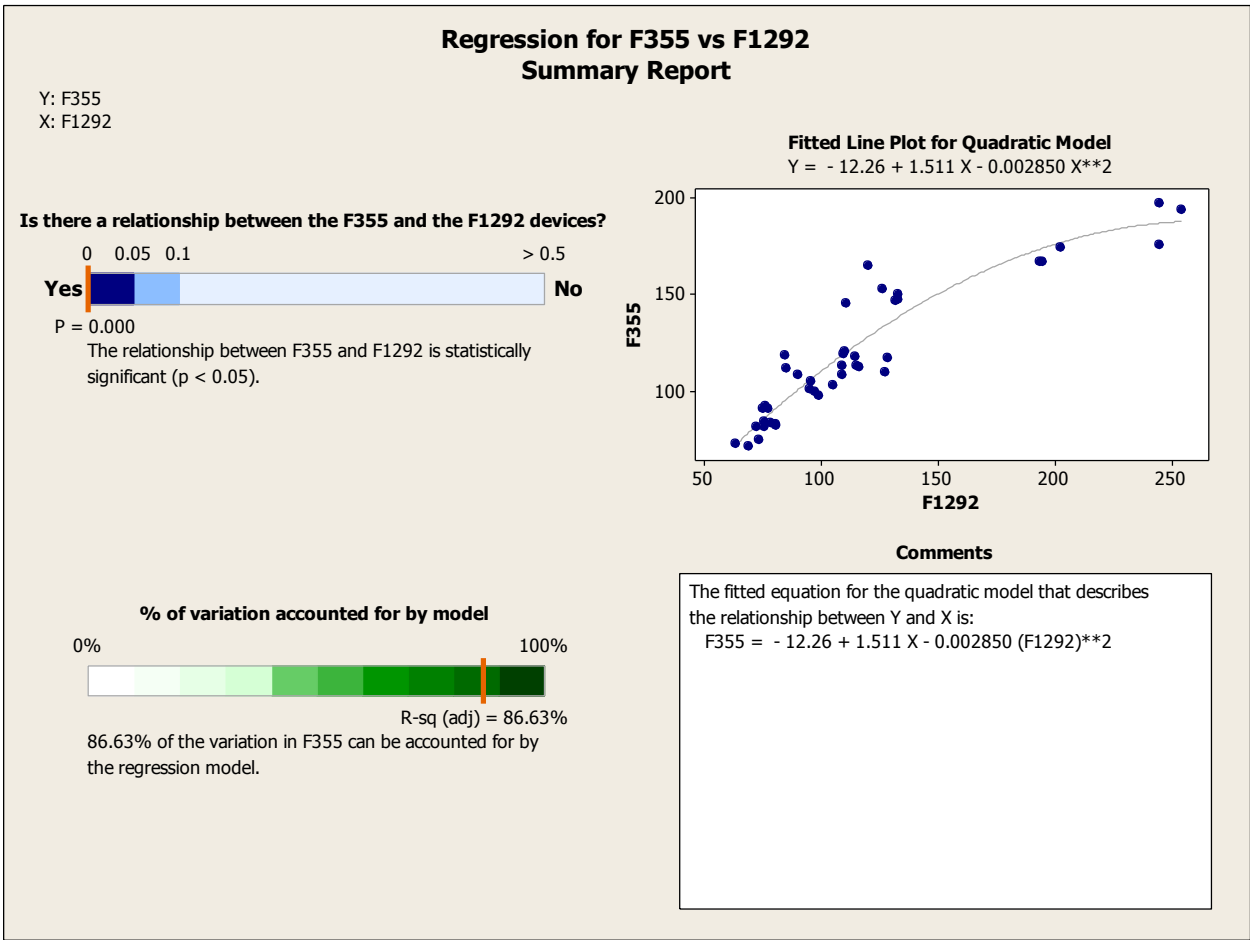

Figure 5. Summary of regression test for the F355 and F1292 devices

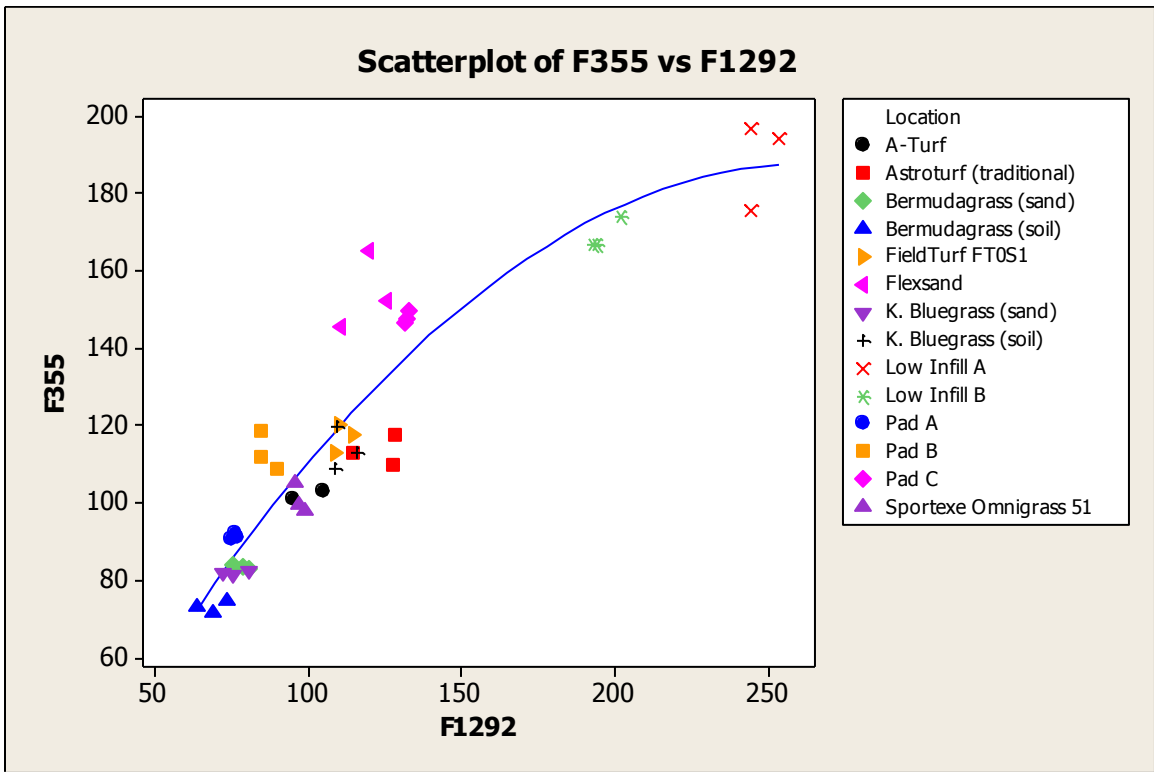

Figure 6. Scatterplot of the relationship between Gmax values obtained with the F355 and F1292 devices with test locations identified

There was a strong relationship between the Gmax values obtained with both test devices. However, the relationship is not linear. Instead the curvilinear, quadratic regression model better fits the data. This indicates that the F1292 device is producing higher Gmax values than the F355 on the harder surfaces with less infill (Low Infill A and B).

F1292 - Clegg Comparison

Because there was only one F1292 device, the mean across all Cleggs was used when comparing the F1292 device to the Clegg. Pad D was not included in the analysis as several testing agencies did not test Pad D. Results of the regression analysis are shown in Figure 7 and each test locations are identified in Figure 8.

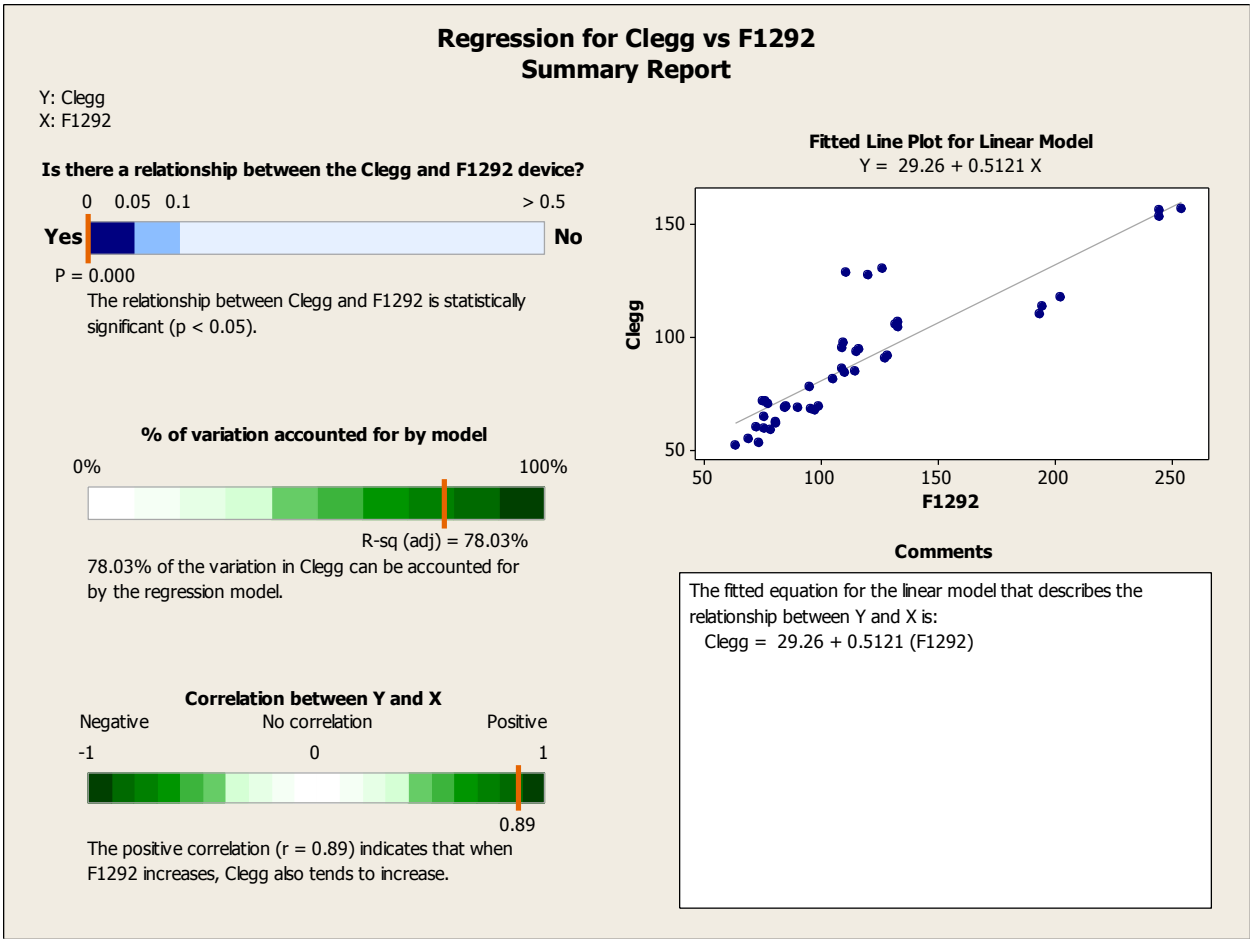

Figure 7. Summary of regression test for the F1292 device and the Clegg

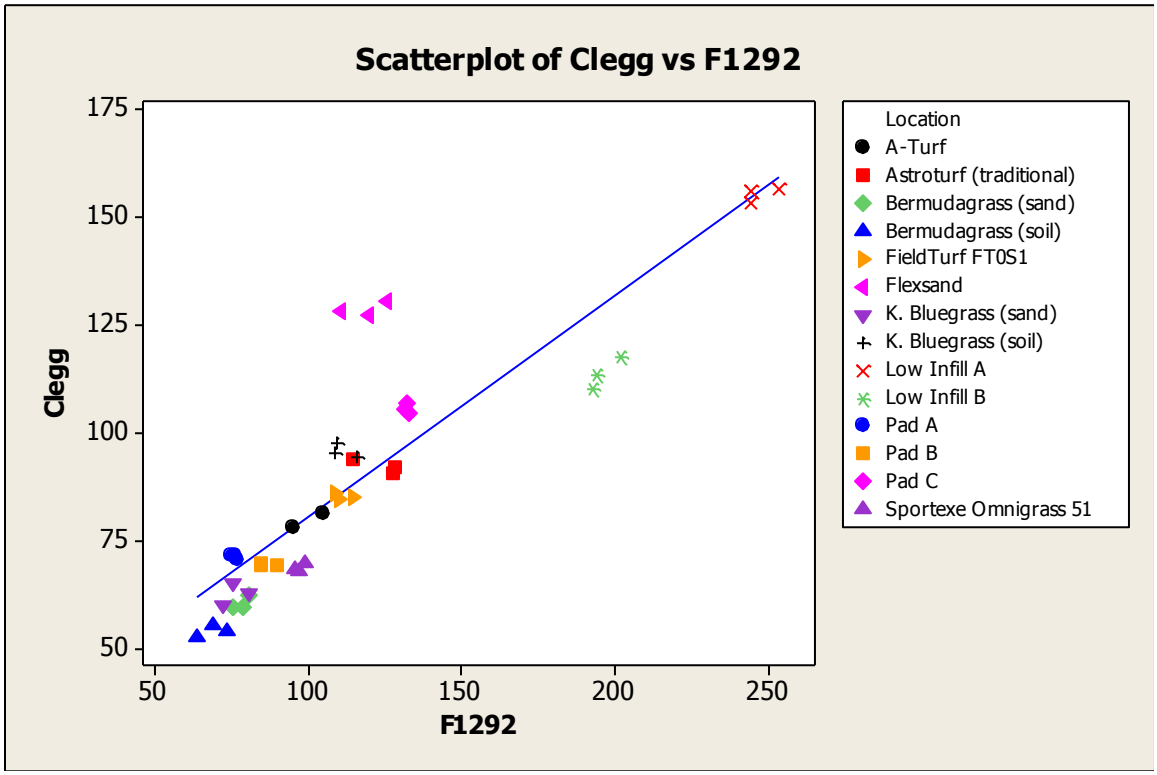

Figure 8. Scatterplot of the relationship between Gmax values obtained with the Clegg and F1292 device with test locations identified

There was a strong relationship between the Gmax values obtained with both test devices. Unlike in the comparison between the F355 and F1292 devices, the Clegg did not produced a lower Gmax relative to the F1292 device on the hardest plot (Low Infill A); however, it did produce a lower Gmax relative to the F1292 device on the Low Infill B plot. Within the typical range of up to 100 Gmax with the Clegg, there is an even stronger linear relationship between the devices.

HIC - Gmax Comparison

F355

Four F355 devices in the round-robin testing also provided HIC data (Agencies A, C, D, and E). The relationship between Gmax and HIC is shown in Figure 9 and test locations are identified in Figure 10.

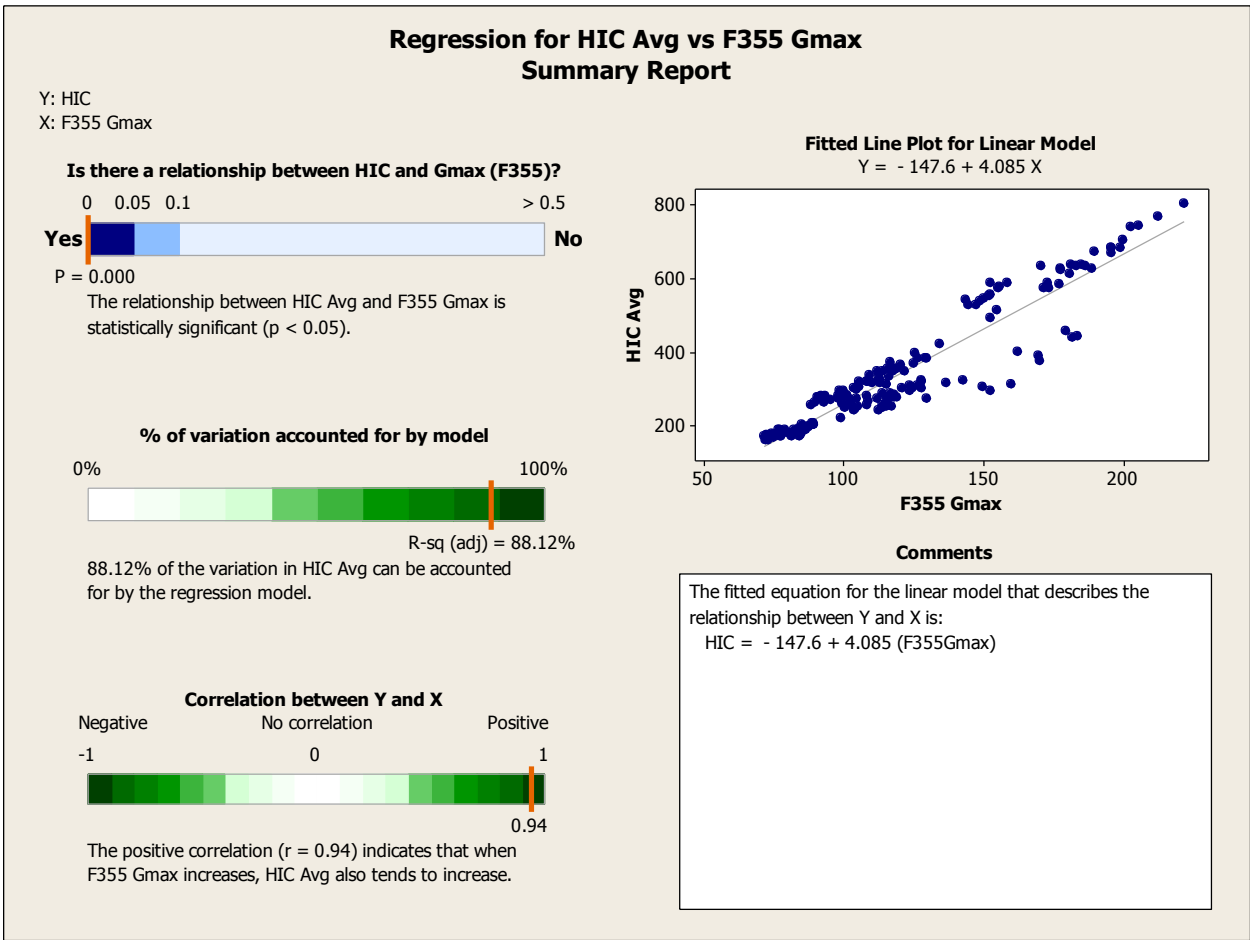

Figure 9. Summary of regression test for Gmax and HIC with the F355 device

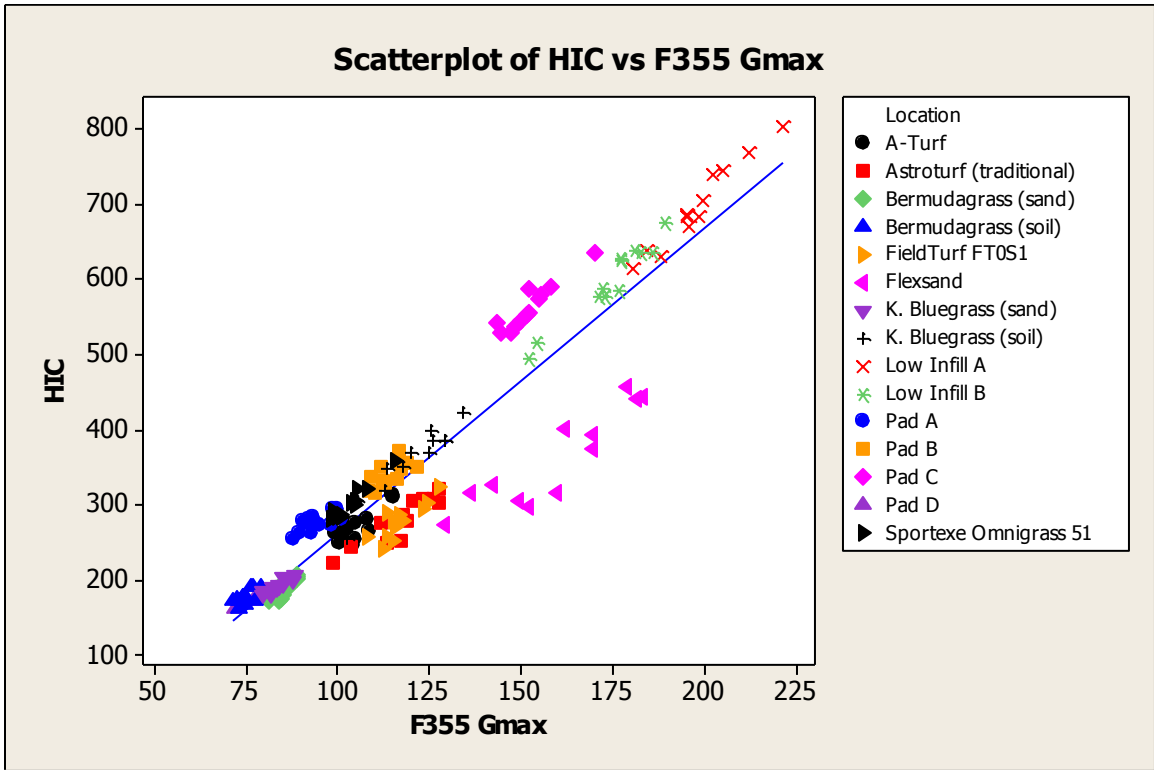

Figure 10. Scatterplot of the relationship between Gmax and HIC using the F355 device with test locations identified

There was a strong relationship between the Gmax and HIC when testing with the F355. The Flexsand test location tended to produce a lower HIC value relative to Gmax while all other test plots exhibited a very strong linear relationship.

There was a strong relationship between the Gmax and HIC when testing with the Clegg. The disparity between Gmax and HIC that existed on the Flexsand plots when tested with the F355 devices was not present when testing with the Clegg.

F1292

The only F1292 included in the round-robin testing was operated by Agency E. The relationship between Gmax and HIC with the F1292 device is shown in Figure 11 and test locations are identified in Figure 12.

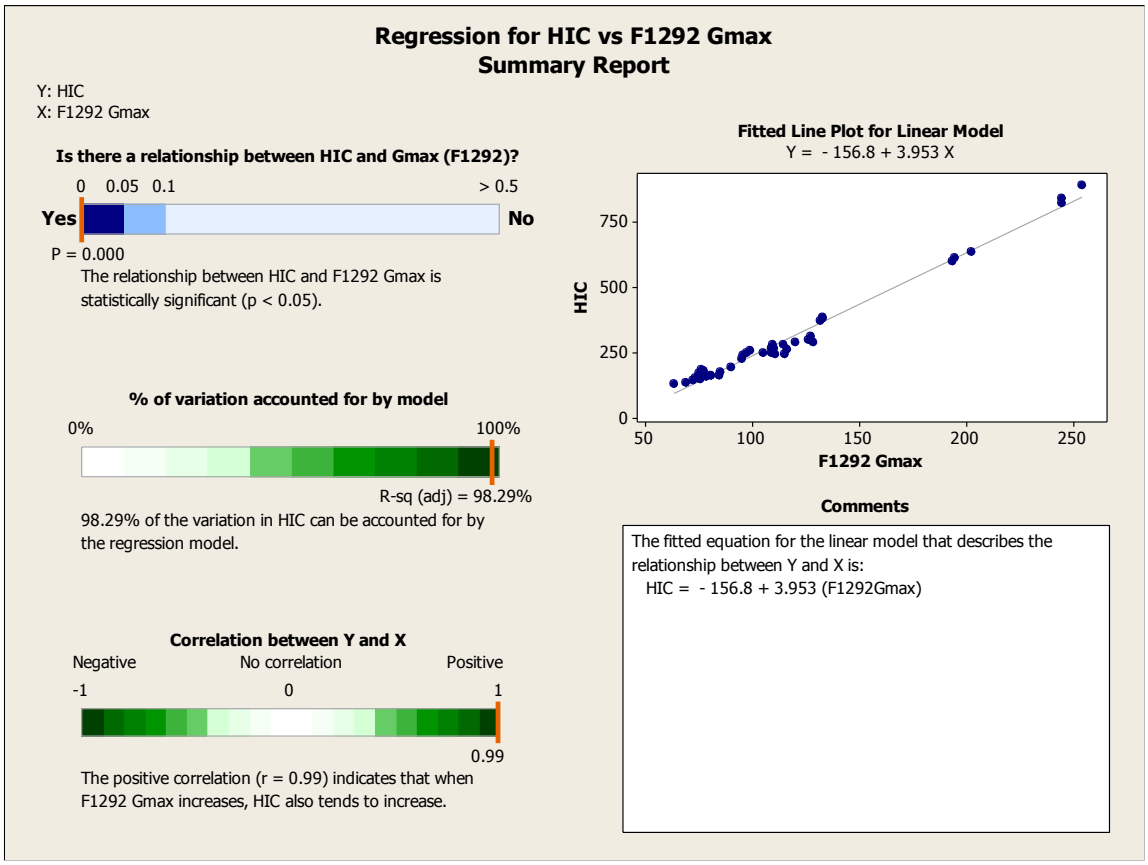

Figure 11. Summary of regression test for Gmax and HIC with the F1292 device

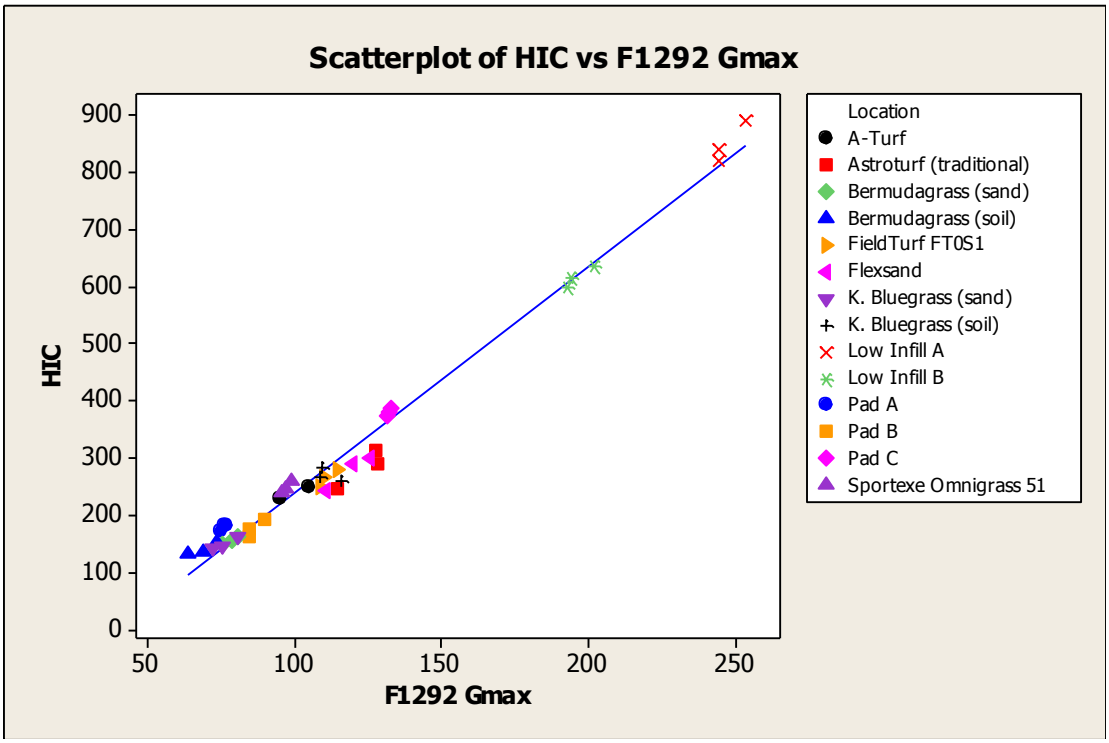

Figure 12. Scatterplot of the relationship between Gmax and HIC using the F1292 device with test locations identified

There was a strong relationship between the Gmax and HIC when testing with the F1292 device.

HIC - SI Comparison

The only F355 devices that collected SI data were the Agency A and Agency D devices. The relationship between HIC and SI with the F355 is shown in Figure 13 and test locations are identified in Figure 14.

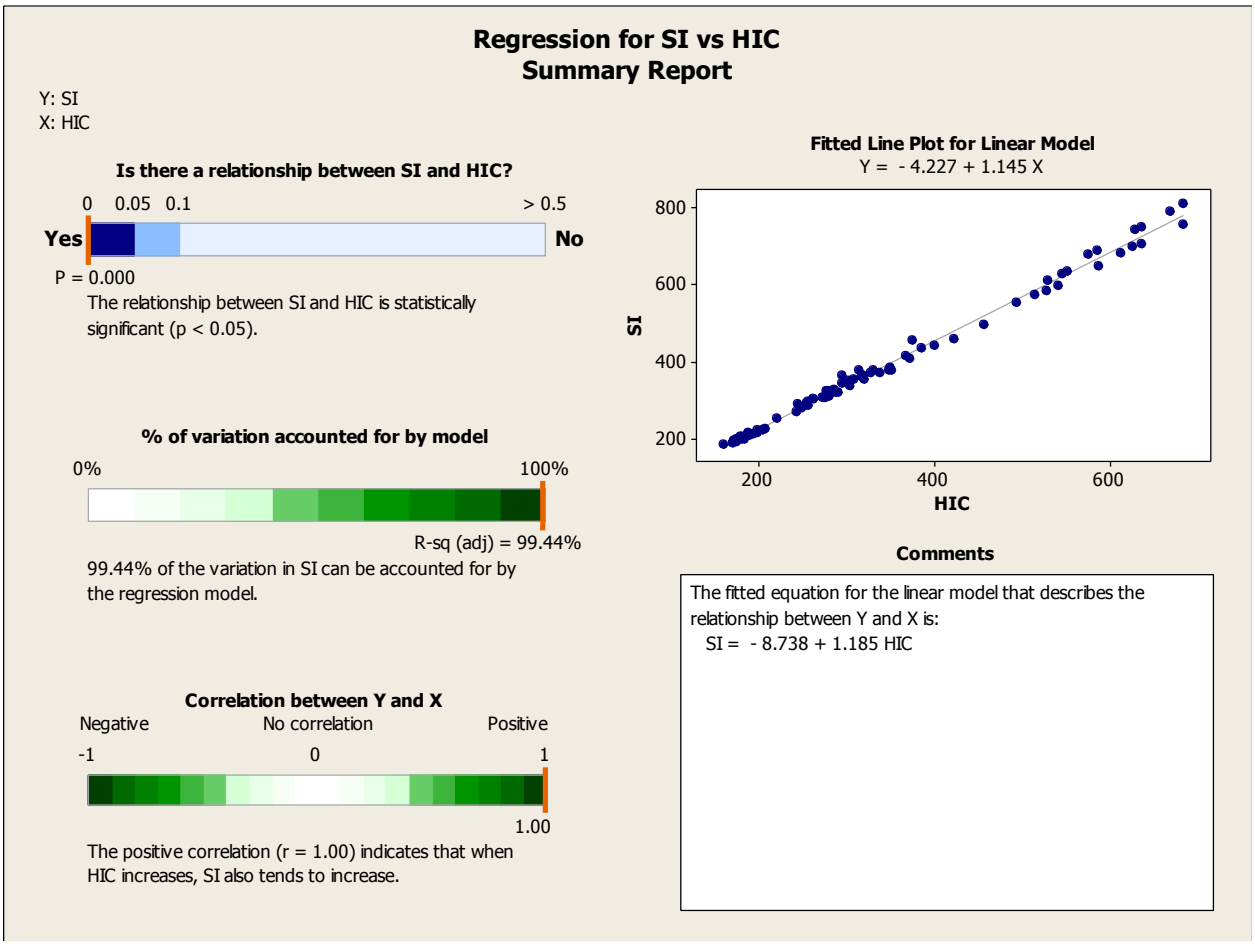

Figure 13. Summary of regression test for SI and HIC with the F355 device

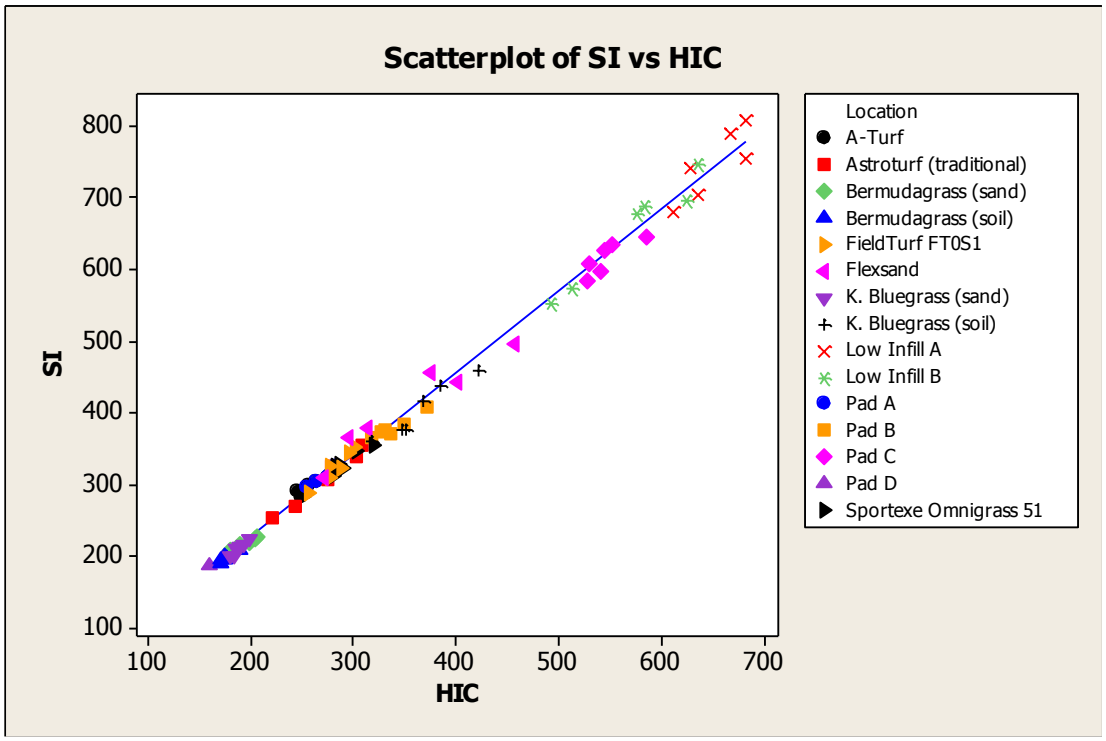

Figure 14. Scatterplot of the relationship between SI and HIC using the F355 device with test locations identified

Vertical Deformation

The only devices that collected vertical deformation data were the Agency D F355 and the Agency D "blue" Clegg. The relationship between the F355 and the Clegg is shown in Figure 15 and test locations are identified in Figure 16.

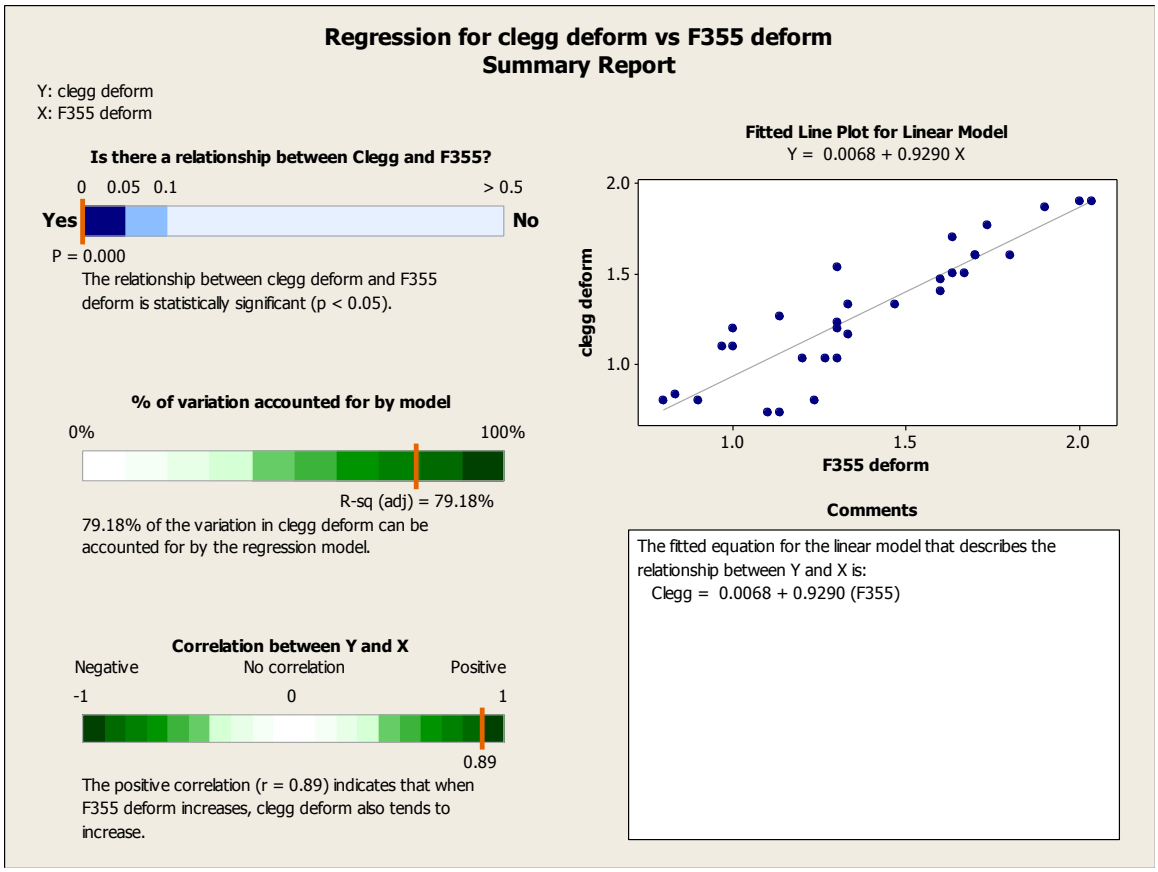

Figure 15. Summary of regression test for the F355 and Clegg for vertical deformation

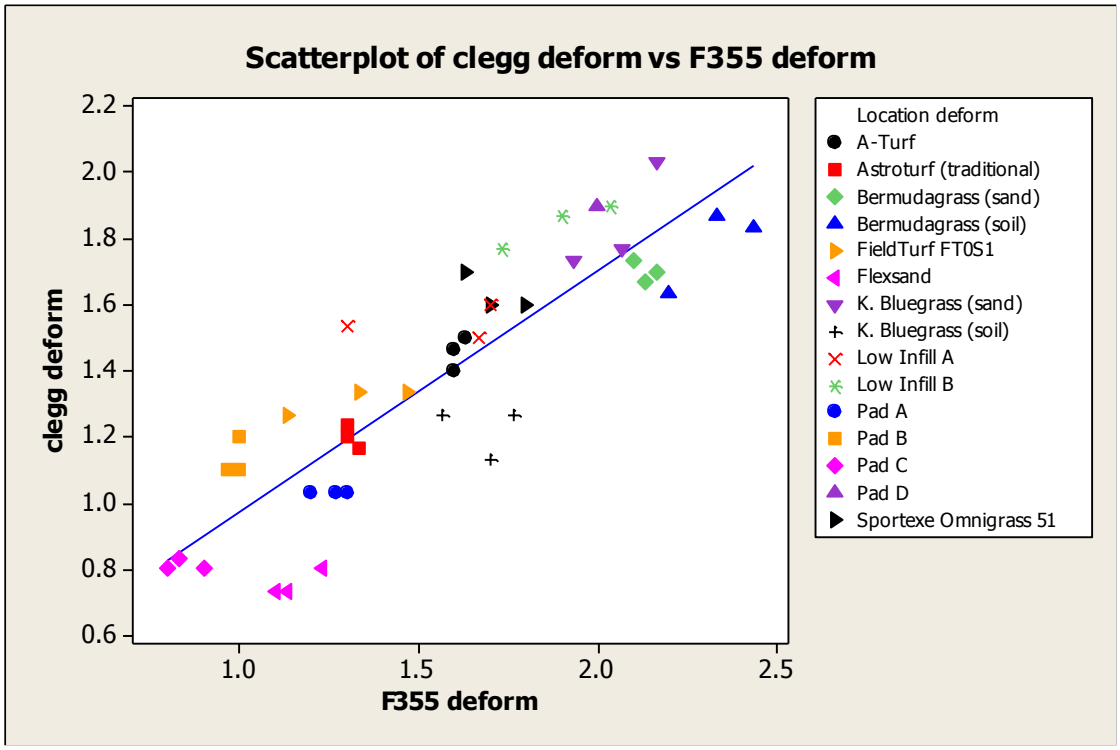

Figure 16. Scatterplot of the relationship between the F355 and Clegg for vertical deformation

Summary

- A higher degree of variation existed among F355 devices than among Cleggs (NFL calibrated)

- All consecutive drops with the F355 were highly correlated and strongly predict one another

- There was a strong relationship between the F355 and Clegg (correlation = 0.89; R-squared value = 79.5%)

- There was a strong (non-linear) relationship between the F355 and F1292 devices (R-squared = 86.6%). The curvilinear relationship indicates that the F1292 device produced higher Gmax values than the F355 on the harder surfaces with less infill compared to lower Gmax surfaces

- There was a strong relationship between the F1292 device and the Clegg (correlation = 0.89; R-squared value = 78.0%)

- There was a strong relationship between Gmax and HIC for the F355 (correlation = 0.94; R-squared value = 88.1) and F1292 device (correlation = 0.99; R-squared value = 98.2%)

- There was a strong relationship between SI and HIC for the F355 (correlation = 1.00; R-squared value = 99.44%)

- There was a strong relationship for vertical deformation between the F355 and Clegg (correlation = 0.89; R-squared value = 79.2%)