Comparing surface firmness measurements on sand-based putting greens

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INTRODUCTION

This research started with the simple question: *What do firmness measurements actually tell us about sand-based putting greens?*

For golf course putting greens, surface firmness is an important component of performance and overall quality. Firmness is a desirable attribute associated with healthy, championship greens; it affects shot-holding capacity, and has implications for durability and resistance to damage. However, discussing firmness often involves vague and subjective language which relies on relative comparisons ("*want firmer greens*"), or speaks to a lack thereof ("*greens are too soft*"). Various devices are available for measuring putting green firmness, and while these measurements alone may be useful for monitoring consistency, to provide meaningful information for guiding maintenance practices, they (also) need to be interpreted in terms of playability.

Previous research has shown a significant relationship ($P \leq 0.05$) between putting green firmness and volumetric water content (VWC), however the variability accompanying those correlations (r^2 = 0.19 to 0.70) underscored the limitations to interpreting and managing firmness exclusively through moisture (Stowell et al., 2009; Linde et al., 2011). In these studies, variability was partially attributed to VWC measurements having been taken at a 12 cm depth below the surface; additionally, work by Linde et al. encompassed samples from 53 golf courses, and differences in turfgrass variety, verdure, thatch, soil texture, and bulk density (BD) were all listed as potential contributing factors.

Recently, measurement devices for both VWC and firmness have expanded to include (i) new methods of quantifying firmness, and (ii) new depths at which VWC can be measured (closer to the surface). The Clegg Impact Soil Tester (CIST) and USGA TruFirm meter used in previous research both utilized an accelerometer for measuring firmness; a redesigned version of the TruFirm now presents an alternative method for quantifying firmness. Portable moisture meters can now measure VWC within 1.3 and 2.5 cm of the putting surface (in addition to 3.8 cm). These new measurements present an opportunity to revisit the firmness/VWC comparisons and examine: (i) the extent to which previously reported relationships hold true, and (ii) how much firmness measurements (continue to) provide unique information, especially to superintendents already using a TDR meter at shallow depths.

This research sought to examine firmness measurements from three distinct perspectives, those of: (i) golf course superintendents, (ii) turfgrass researchers, and (iii) golfers. This approach allowed firmness measurements to be discussed in terms of (i) maintenance practices, (ii) physical constituents of the putting surface, and (iii) playability. To address the superintendents' perspective, the work focused on side by side **comparisons of measurement devices**; for turfgrass researchers, the focus was on comparisons with **ground truth data**; and the golfers' perspective focused on the results of **golf ball/putting surface impact**.

The objectives of this research were to compare surface firmness measurements from each device to: (i) each other, as well as moisture meter measurements at 1.3, 2.5, and 3.8 cm depths; (ii) ground truth data for VWC, organic matter (OM), and BD; (iii) ball mark severity. Exploring methodology to precisely and efficiently measure golf ball bounce was an additional consideration during the third objective.

MATERIALS & METHODS

All research was conducted at the University of Arkansas Agricultural Research & Extension Center in Fayetteville, AR on a mature creeping bentgrass (*Agrostis stolonifera* L. cv. Penn A1) research putting green, with a USGA sand-based rootzone (USGA Green Section Staff, 2004). Turfgrass was mowed 6X weekly at 3.2 mm, foliar applications of nitrogen fertility (46-0-0 urea) at 12.2 kg ha^{-1}, and trinexapac-ethyl at 0.024 kg a.i. ha^{-1}, along with sand topdressing occurred every 14d throughout the growing season; Revolution wetting agent (Aquatrols, Paulsboro, NJ) was applied at 19.1 L ha^{-1} every 28d.

The experimental area consisted of 16 independent irrigation zones (3.7 x 3.7 m) and a combination of *irrigation x rolling* treatments were used to create a range of firmness and VWC conditions. Net evapotranspiration (ET = Et_o – precipitation) served as the basis for irrigation treatments, which were applied daily as 50, 75, 100, and 125% ET replacement. Rolling treatments were applied with a **Tru-Turf greens roller** (RS48-11C, Tru-Turf, Queensland, Australia) 0, 3, or 6 times weekly (equivalent to 0, 6, or 12 down-and-back passes). Treatments were initiated on 25 June 2017 and final data collection occurred on 16 September 2017.

Firmness measurements were made using (i) the **Clegg Impact Soil Tester** with 2.25 kg hammer (Model 95049A, Lafayette Instrument Company, Lafayette, IN), and (ii) the **FieldScout TruFirm Turf Firmness Meter** (Item# 6490S, Spectrum Technologies Inc., Aurora, IL). A single drop per location was used for each device; CIST measurements were reported as G_{max} and TruFirm measurements in mm. In situ VWC was measured with **FieldScout TDR 350 Soil Moisture Meter** equip with **TDR Turf Rod Spacer** (Item#s 6435 & 6435SP, Spectrum Technologies Inc.). Measurements were made at 1.3, 2.5, and 3.8 cm depths, and all TDR readings were reported as the *Period Mode* value in microseconds (µs).

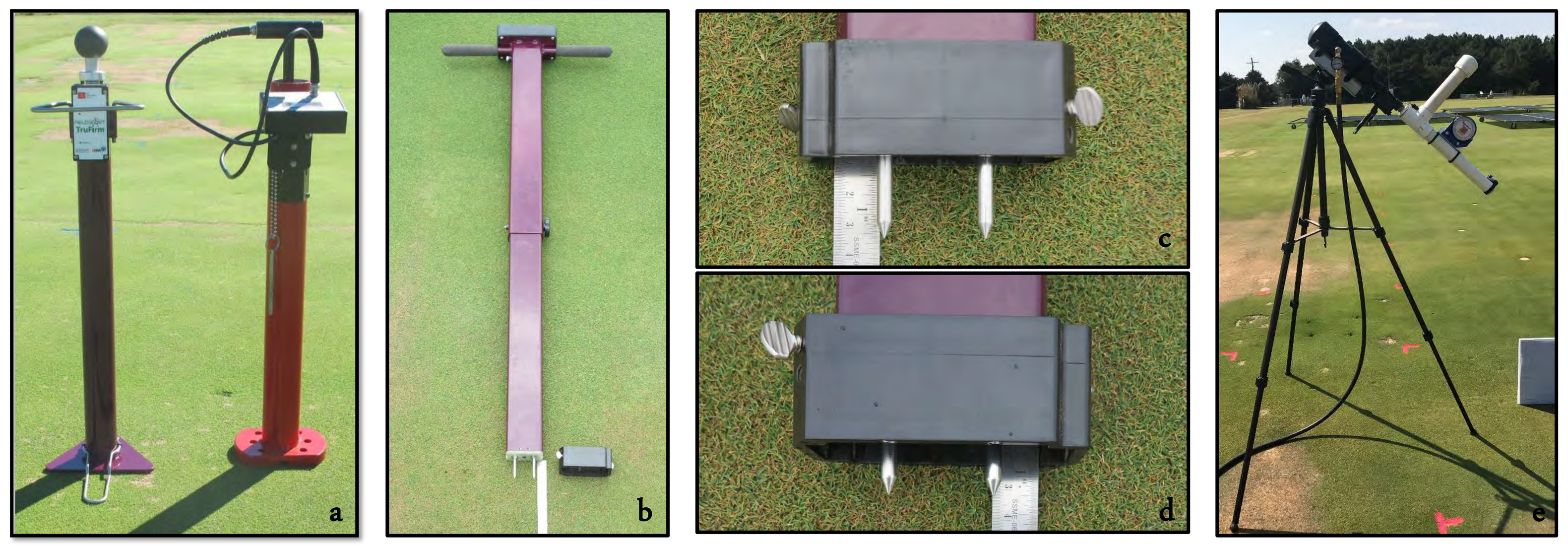

Image 1 (a): FieldScout TruFirm Turf Firmness meter (left) and Clegg Impact Soil Tester (right); (b): FieldScout TDR 350 Soil Moisture Meter with 3.8 cm rods; Turf Rod Spacer next to meter; (c): TDR 350 fit with Turf Rod Spacer for 2.5 cm depth; (d): TDR 350 fit with Turf Rod Spacer for 1.3 cm depth; (e) pneumatic golf ball launcher used to create golf ball/putting surface impact.

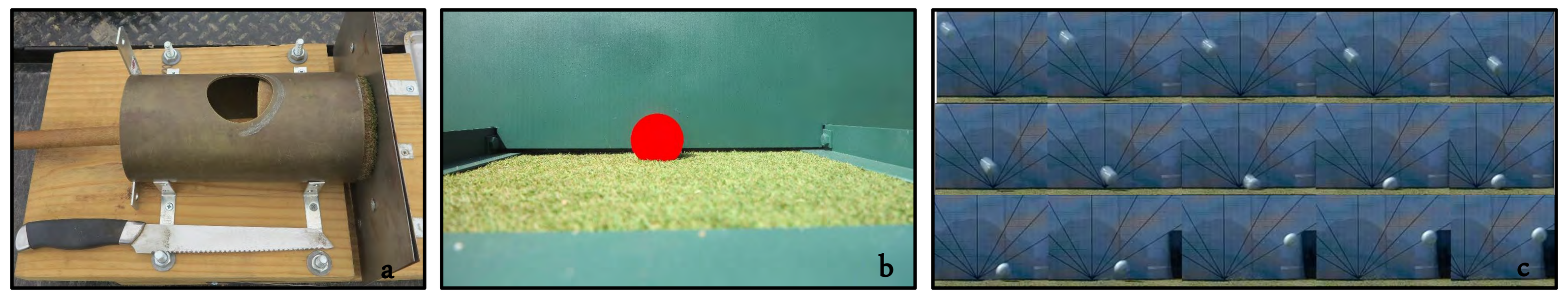

Image 2: (a) Extracted putting green sample prior to cutting (and weighing) surface 1.3 cm section; (b) digital image analysis overlay used to calculate ball mark severity; (c) sequential images from high speed video of golf ball/putting surface impact from pneumatic golf ball launcher.

Materials & Methods continued

Comparison of measurement devices were collected in a manner representative of typical golf course maintenance operations. Firmness and VWC measurements were taken in close proximity to each other, but not necessarily in the same precise location on the green. A single drop of the (i) CIST and (ii) TruFirm were made approx. 10 cm apart. For each VWC sampling depth, TDR measurements were made adjacent to firmness measurements, so that all data were collected within a 7.5 cm radius and each measurement location was characterized by a single TruFirm, CIST, and TDR value (for each depth).

Ground truth data were collected so that firmness measurements could be compared to relative amounts of water, OM, and solid constituents physically present at, and just below the putting surface. Care was taken to align the TDR rods so that the same two holes were used for each measurement depth (1.3, 2.5, 3.8 cm – in that order). The TruFirm meter was subsequently centered over the two holes and a single hammer drop was recorded. A cup-cutter (Item# RP1001, R&R Products Inc., Tucson, AZ) was used to extract a 10.8 cm diameter sample centered around the measured area. Samples were immediately sliced into three 1.3 cm sections (starting at the surface) and each sample was individually weighed. Gravimetric procedures (drying at 105°C for 24 h) were used to calculate VWC and BD and loss on ignition methods (500°C for 6 h) were employed to calculate OM. Within each plot, above procedures were repeated in a separate location using CIST.

Golf ball/putting surface impact were the means of connecting firmness measurements to playability, and represented putting green quality, as experienced by the end users. A pneumatic golf ball launcher (Young et al., 2017) was used to create all golf ball impacts, using Titleist ProV1x golf balls. Based on ranges identified by Whitlark and Pringle (2012), barrel angle was adjusted to 45° resulting in a discharge point 95 cm above the putting surface. Operating pressures of 103, 138, and 172 kPa were evaluated, based on visual assessments for "typical" or "expected" ball mark severity; data from each operating pressure were analyzed separately. Surrounding each ball impact location four CIST, TruFirm, and TDR measurements (at each depth) were made. Digital image analysis (DIA) for ball mark severity (Young et al., 2012) was carried out using a modified camera platform with **Canon Powershot G1X** camera (Canon USA Inc., Melville, NY) and **Sigma Scan Pro** (version 5.0, Systat Software Inc., San Jose, CA). High speed video of golf ball impact was recorded with **Casio Exilim EX-F1** camera (Casio Computer Co. LTD., Tokyo, Japan); videos were trimmed and viewed within **Windows Movie Maker** (Version 2012, Microsoft Corp.) and converted to still images using **VLC media player** (version 2.2.6, VideoLAN Organization, Paris, France).

Statistical analysis was performed using **SAS 9.4** (PROC REG, SAS Institute, Cary, NC).

RESULTS & DISCUSSION

Fig. 1 - Firmness measurement devices

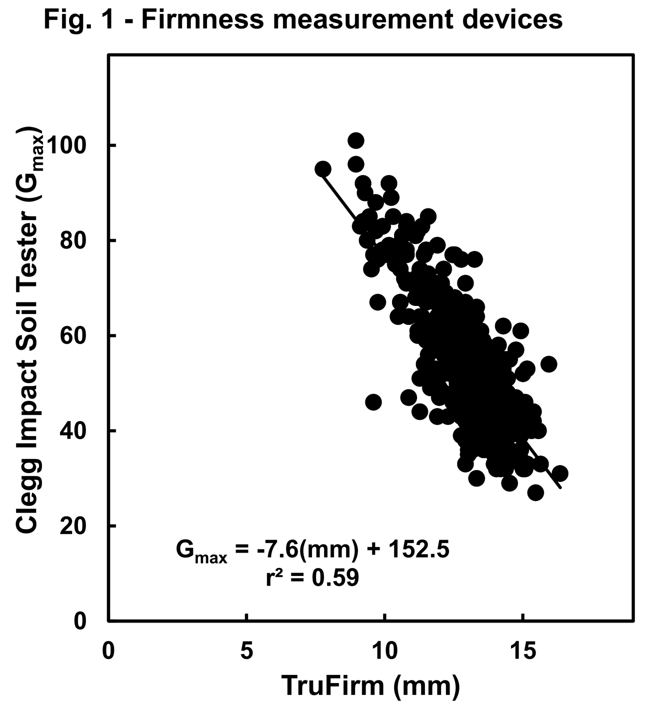

Fig. 1: All corresponding firmness measurements from 2017 using Clegg Impact Soil Tester (CIST) and FieldScout TruFirm meter. A highly significant linear relationship ($P \leq 0.0001$) was observed from a total of 2508 paired measurements; CIST ranged from 27 to 101 G_{max} ($\bar{x}$ = 53); TruFirm ranged from 8 to 16 mm ($\bar{x}$ = 13). A single drop per location was made with each device.

Table 1. Relationships among firmness measurements and TDR350

TDR350 depth (cm)	Clegg Impact Soil Tester *P* value	r²	Std. error	TruFirm *P* value	r²	Std. error
1.3	≤0.0001	**0.43**	9.6	≤0.0001	**0.30**	1.1
2.5	≤0.0001	**0.56**	8.4	≤0.0001	**0.44**	1.0
3.8	≤0.0001	**0.61**	7.9	≤0.0001	**0.48**	0.9

For all TDR350 depths n=835

Table 2. Golf ball/putting surface impact

	Ball mark severity %					
	103 kPa ($\bar{x}$=3.63, n=5)		138 kPa ($\bar{x}$=8.22, n=8)		172 kPa ($\bar{x}$=9.61,n=4)	
Device	*P* value	r²	*P* value	r²	*P* value	r²
CIST	0.3847	0.26	0.1180	0.36	**0.0255***	**0.95**
TruFirm	0.2088	0.46	0.0762	0.43	**0.0409***	**0.92**
TDR350 (1.3 cm)	0.2364	0.42	**0.0022***	**0.81**	0.0660	0.87
TDR350 (2.5 cm)	0.3101	0.33	**0.0025***	**0.81**	0.0595	0.88
TDR350 (3.8 cm)	0.3274	0.31	**0.0069***	**0.73**	**0.0284***	**0.94**

** Indicates measurements were a significant predictor of ball mark severity (P ≤ 0.05)*

Table. 1: Firmness measurements using Clegg Impact Soil Tester and TruFirm were compared to TDR 350 measurements at three different depths. **Table 2**: Firmness and moisture measurements as a predictor of ball mark severity from a pneumatic golf ball launcher. Four measurements with each device were made within a 25 cm radius of ball impact and averaged. Severity % determined through digital image analysis.

Fig. 2 – Ground truth data from extracted putting green samples

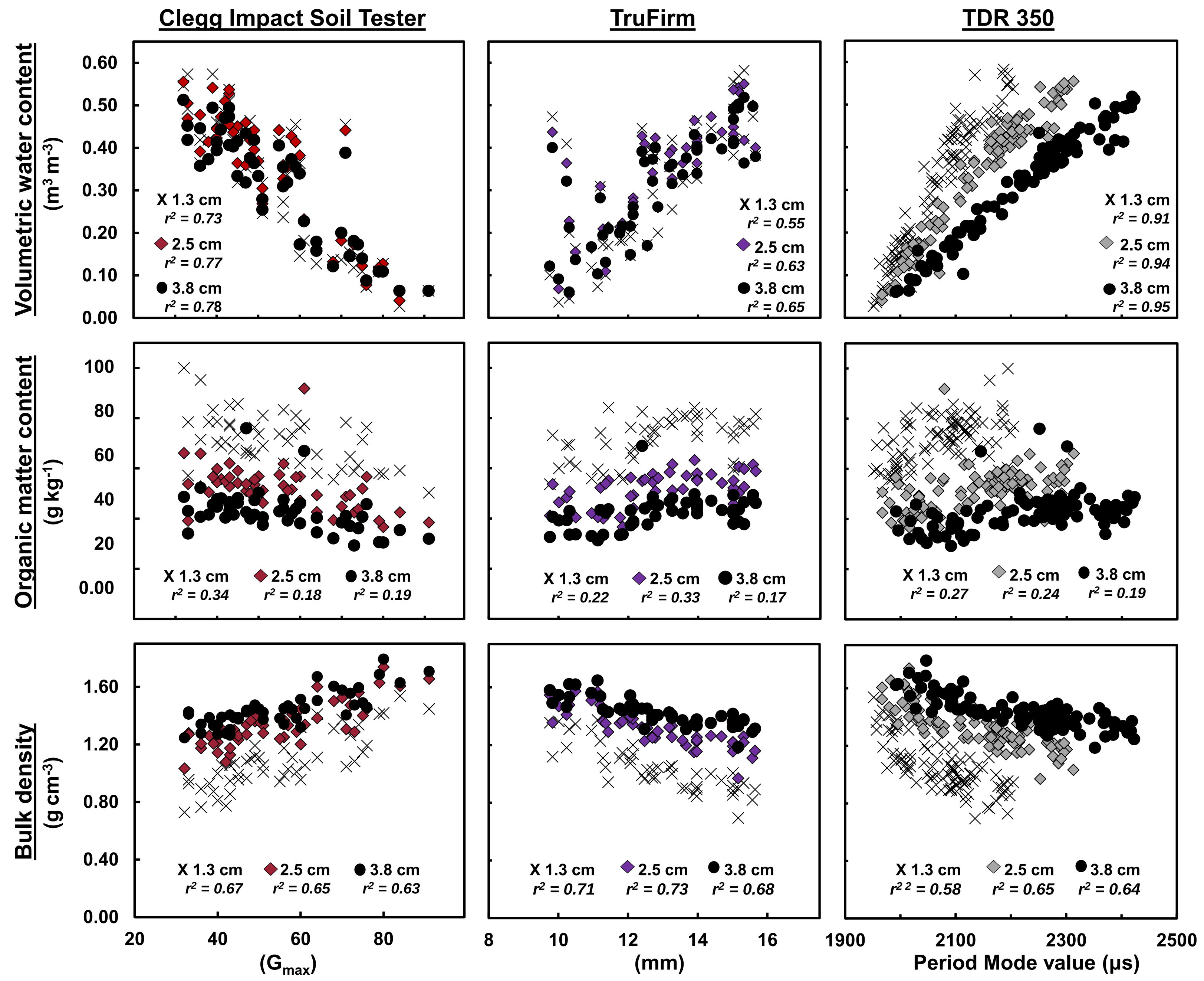

Fig. 2: The relationships between measurement devices and ground truth data for volumetric water content, organic matter content, and bulk density within the uppermost 1.3, 2.5, and 3.8 cm of a creeping bentgrass, USGA sand-based putting green.

Results & Discussion continued

For **comparisons of measurement devices**, a highly significant inverse linear relationship ($P \leq 0.001$) was observed between CIST and FieldScout TruFirm, with r^2=0.59 (Fig. 1). These results indicated a weaker relationship between devices than was reported by Stowell et al. (2009), using a single drop of the CIST and USGA TruFirm meter (r^2=0.71). The weaker relationship in this research may be attributed to differences in the specific measurements being performed by the two devices, as the FieldScout TruFirm measures linear distance (displacement) rather than (negative) acceleration. Highly significant linear relationships were observed between both firmness devices and the TDR 350 at all depths (Table 1). The CIST had greater r^2 values than TruFirm at each depth, with max r^2 of 0.61 at the 3.8 cm depth (Table 1).

For **ground truth data**, all three devices had significant linear relationships ($P \leq 0.05$) with VWC, OM, and BD, at each sampled depth. Predicting VWC from firmness measurements resulted in r^2 ranging from 0.73 to 0.78 for CIST, and 0.55 to 0.65 for TruFirm, while the TDR350 r^2 ranged from 0.91 to 0.95; for all devices, r^2 increased with increasing depth (Fig. 2). Organic matter had the weakest correlation to all devices, with an r^2 range of 0.17 to 0.34. (Fig. 2). Bulk density produced similar r^2 values among all three devices; TruFirm had the strongest relationship with bulk density (r^2= 0.71) at the 2.5 cm depth (Fig. 2).

For **golf ball/putting green impact**, strongest correlations were observed for shots fired at 172 kPa, at which CIST, TruFirm, and TDR 350 (3.8 cm) were all significant predictors of ball mark severity ($P \leq 0.05$), with r^2 of 0.95, 0.92, and 0.94 respectively (Table 2). High speed video data was limited due to tradeoffs between frames per second and image dimensions. In addition to identifying settings capable of producing appropriate golf ball speeds, future research should also evaluate consistency of pneumatic golf ball launcher.

CONCLUSIONS

For sand-based putting greens, firmness measurements were significant predictors of VWC near the surface, however they lacked the same level of precision as the TDR 350 at all sampled depths. Both firmness meters exhibited a stronger relationship with bulk density than the TDR. These results indicated that firmness measurements should not be considered redundant of TDR data at shallow depths. For superintendents effectively managing firmness through moisture and rolling, firmness devices may be best utilized in conjunction with TDR meters (rather than as alternatives to them).

Future research focusing on the spatial and temporal consistency of firmness measurements has potential to identify (i) appropriate number of measurements needed to characterize a given area, and (ii) changes in firmness occurring throughout the day - as affected by ET and turfgrass physiology. While high speed video produced images from which golf ball speed, bounce angle, and spin may be observed and estimated, directly measuring these parameters may be possible using current technology, thus introducing greater precision and efficiency into the process. Ultimately, correlating firmness to playability requires more data accurately depicting golf ball response to the moment of impact, in addition to ball mark severity.

REFERENCES

Linde, D. T., L. J. Stowell, W. Gelernter, and K. McAuliffe. 2011. Monitoring and managing putting green firmness on golf courses. [Online]Applied Turfgrass Science doi: 10.1094/ATS-2011-0126-01-RS.
Stowell, L., P. Gross, W. Gelernter, and M. Burchfield. 2009. Measuring greens firmness using the USGA TruFirm and the Clegg Soil Impact Tester at Victoria Country Club: A preliminary study. [Online] Available at http://www.paceturf.org/PTRI/Documents/0901 sj.pdf (verified 09/28/2010). San Diego, California: PACE Turfgrass Research Institute.
United States Golf Association Green Section Staff. 2004. USGA Recommendations for a Method of Putting Green Construction. [Far Hills, NJ: United States Golf Association].
Whitlark, B., and M. Pringle. 2012. Can't stop your ball on the green?: Are the greens to blame or is it your game?. USGA Green Sec. Rec. 50(25):p. 1-3.
Young, J., M. Richardson, and D. Karcher. 2017. Golf ball mark severity and recovery as affected by mowing height, rolling frequency, foot traffic, and moisture. Agron. J. 109(4):p. 1758-1764.
Young, J., M. Richardson, and D. Karcher. 2012. Evaluating ball mark severity and recovery using digital image analysis. Arkansas Turfgrass Rep. 2010. Arkansas Agric. Exp. Stn. Res. Ser. 593:50–55.

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