Thatch Accumulation in Zoysiagrass Genotypes across the US Transition Zone and Southern Regions

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Abstract. Thatch is an intertwined layer of dead and living stems and roots that accumulates in turfgrass when organic matter production outpaces decomposition, affecting turfgrass quality and playability. This study evaluated thatch accumulation and performance of various zoysiagrass (*Zoysia* spp.) genotypes across six locations (Olathe, KS, USA; Stillwater, OK, USA; West Lafayette, IN, USA; Dallas, TX, USA; and Davie and Citra, FL, USA) for the National Turfgrass Evaluation Program (NTEP) and United States Golf Association (USGA) trials. Thatch accumulation in the NTEP trial was measured 5 years after planting, while the USGA trial was assessed 3 years after planting. The objectives were to 1) evaluate thatch accumulation across cultivars and breeding genotypes and 2) evaluate the correlations between zoysiagrass thatch depth vs. other genotype morphological traits. Thatch depth, thatch mass, turfgrass quality, and other traits were measured across locations. In the NTEP trial, significant differences in thatch depth among cultivars were observed only in Dallas, TX, where 'Emerald' had the highest thatch depth (0.73 inch) and 'Meyer' and DALZ 1808 had the least (<0.35 inch). The USGA trial showed no significant thatch depth differences in Olathe, KS, and West Lafayette, IN, but minor variations were noted in Citra, FL. Correlations between thatch depth and other traits showed that thatch depth was negatively correlated with surface firmness at Dallas, TX, and Citra, FL, locations (NTEP trial) and with Normalized Difference Vegetation Index (NDVI) in West Lafayette, IN (USGA trial). Positive correlations with thatch depth were found with tiller numbers in Stillwater, OK; Dallas, TX; and Davie, FL (NTEP trial) and were positively correlated with the thatch mass in Olathe, KS (USGA trial). Environmental conditions could impact the performance of zoysiagrass genotypes, although these conditions were not considered in this study. The correlations noted at each location give guidance on what may impact thatch development or its influence over time.

Thatch, a layer of dead and living stems and roots between the soil surface and the green vegetation (Beard 1973; McCarty 2018), occurs naturally when organic matter accumulates faster than it decomposes (Couillard and Turgeon 1997). Excessive thatch can reduce turfgrass quality, playability, pesticide efficacy, and water infiltration (McCarty et al. 2016). Thatch dries quickly and is difficult to rehydrate, making it an unsuitable medium for root development. The wear resistance of the turfgrass produced by foot traffic or equipment use may be improved by a thin layer of thatch, which also acts as a buffer against temperature and moisture extremes. However, excessive thatch accumulation may negatively impact the turfgrass performance over time.

Thatch is primarily composed of cellulose, hemicellulose, and lignin (Ledeboer and Skogley 1967), which affect its rate of decomposition. The high lignin content slows microbial breakdown, leading to accumulation (Couillard and Turgeon 1997). Turfgrass species that produce significant amounts of lignified structures, such as lateral stems and vascular strands, tend to contribute more to thatch development (Ledeboer and Skogley 1967). In high turfgrass maintenance settings, such as golf course putting greens, fairways, and tees, plant tissues may decompose at a slower rate than they are produced, leading to excessive thatch buildup over time (Weaver et al. 2022).

Scalping of the turfgrass can occur when mowers are driven unevenly on thatched turfgrass, leading to inconsistent surface heights. This surface irregularity affects both mowing quality and playability. Deep thatch layers can create an uneven footing, making it uncomfortable to walk on and increasing the risk of unstable balance on golf course fairways and tees (Dunn et al. 1981). Thatch management is an important practice to ensure acceptable turfgrass quality and performance. Various methods of measuring thatch include weight loss-on-ignition for organic matter, rulers for depth, balances for weight, and thatch meters for compression (Shaddox and Unruh 2019).

Zoysiagrass (*Zoysia* spp. Willd.) is a warm-season perennial sod-forming species that is well adapted for use as a turfgrass in the transitional and southern regions of the United States (Patton et al. 2017). Zoysiagrass is of particular interest due to its increasing use on golf courses, home lawns, and commercial sites throughout the transition zone and southern United States. Its growth habit, which includes lateral stems and high lignin content, can contribute significantly to thatch buildup (Patton et al. 2017).

Multienvironment trials are conducted to assess genotype performances across environments (years, locations, or seasons). The aim is to select the best and superior genotypes across different environmental conditions and for specific environments (Annicchiarico 2002; Comstock 1977; Smith et al. 2005). Zoysiagrass breeding efforts across multiple breeding programs have focused on improving traits such as turfgrass quality, salt and drought tolerance, tolerance to extreme temperature, shade tolerance, and biotic stress resistance (Braun et al. 2021, 2022). Thatch accumulation is also an important trait to evaluate when breeding zoysiagrass. All breeding programs aim to develop regionally adapted cultivars to broaden the use of zoysiagrass. In 2019, 39 genotypes sponsored by the NTEP were established in six different geographical locations, and 74 genotypes sponsored by the United States Golf Association (USGA) were established in three geographical locations. The objectives of this study were to 1) evaluate the variability of thatch accumulation among several zoysiagrass genotypes and cultivars from these diverse geographical locations; and 2) evaluate the correlations between zoysiagrass thatch depth and other genotype morphological traits.

Materials and methods

Research site information

Experimental studies to evaluate thatch accumulation and turfgrass morphological characteristics in 2024 were done on breeding genotypes and commercialized cultivars in NTEP and USGA trials. Before planting plugs, the soil was prepared by tilling and leveling. At all locations, plugs were planted in randomized complete block experiments with individual plots measuring 5 × 5 or 6 × 6 ft with a 1- or 2-foot-wide alleyway between all plots. Approximately 24 plugs measuring 2 × 2 inches were planted in individual plots for both studies. The NTEP trial was initiated in 2019 in Olathe, KS; Stillwater, OK; West Lafayette, IN; Dallas, TX; and Davie and Citra, FL (Table 1; Fig. 1), hereafter referred to as Olathe, Stillwater, West Lafayette, Dallas, Davie, and Citra. Thirty-nine zoysiagrass genotypes and cultivars were planted across all locations, comprising four commercial cultivars and 35 experimental breeding genotypes. However, only four breeding genotypes and four commercial cultivars were selected for the thatch measurements due to their overall excellent performance as evaluated by NTEP in comparison with 'Meyer' zoysiagrass, the oldest cultivar (Fry and McFadden 2022; Patton et al. 2017). These were 'Meyer', 'Emerald', 'Zeon', 'Empire', DALZ 1808, DALZ 1311, DALZ 1701, and FAES 1319 (now cultivar Brazos) (Chandra et al. 2023).

The USGA experiment was initiated in 2021 in Olathe, KS; West Lafayette, IN; and Citra, FL (Table 2), hereafter referred to as Kansas, Indiana, and Florida. Seventy-four genotypes and cultivars were established across these locations, including five commercial and 69 experimental breeding genotypes. Like the NTEP trial, only those treatments that were considered to have excellent performance according to the USGA standards in the southern United States and transition zone were selected for the thatch measurements (Chandra et al. 2023; McFadden 2024). In Kansas, 14 genotypes, including DALZ 1701, DALZ 1808, 6782-75, 6782-79, 6782-104, 6829-36, 6844-36, 6844-74, 6844-104, 6844-150, 6844-202, 'Meyer', 'Innovation', and 'Emerald' were selected. In Florida, 12 genotypes, including 6829-69, 6941-36, 6782-75, 6942-22, 6782-104, 6785-19, 6789-23, 6792-44, 6789-40, DALZ 1701, Zeon, and 'Palisades', were selected. In Indiana, 12 genotypes, including 6844-74, DALZ 1701, 6844-150, 6829-36, 6844-36, 6844-104, 6844-202, DALZ 1808, 'Palisades', 'Meyer', 'Emerald', and 'Innovation', were selected.

Details of each experimental site, including planting date, soil type, fertilization, mowing practices, and irrigation, are presented in Table 1 (NTEP) and Table 2 (USGA). Preemergence herbicides were applied at the onset of planting and routinely every year across all sites, with postemergence herbicides applied routinely throughout the trial period. In addition, some locations used fungicides to control large patch disease. However, details on these were not included in this study.

Data collection and measurement

One 4-inch-diameter plug was collected from each plot (three replications) and thatch depth was measured at three random angles around the plug. Measurements were taken from the base of tillers to the visible base of the thatch using a digital vernier caliper, following established methods (Menchyk et al. 2014; Mu and Carroll 2013; Shaddox and Unruh 2019) (Fig. 1). After counting the number of tillers, the remaining core was washed free of soil and oven-dried at 70 °C for 72 h, and the thatch mass was recorded using an Ohaus Explorer Analytical EX224 balance.

Turfgrass quality, color, density, and texture of field plots were visually rated on a 1 to 9 scale, with higher values indicating better performance. Leaf width was measured with a digital vernier caliper on three randomly selected leaves per plug, and the results were averaged. NDVI (0 to 1 scale, 1 is maximum green color) was recorded to assess plant health and vegetative cover. Surface firmness was measured using a Clegg hammer, expressed in gravities, with higher values indicating firmer turf surfaces (O'Brien et al. 2019).

Data analysis

Data were subjected to analysis of variance using SAS v. 9.4 (SAS Institute Inc., Cary, N, USAC). The MIXED procedure analyzed thatch depth and mass, treating cultivars and locations as fixed effects, with replicates nested within locations as a random effect. The GLIMMIX procedure examined genotype performance within locations to evaluate location-specific effects. Pairwise comparisons were performe using Tukey's adjustment at $P \leq 0.05$. Correlations among traits, including thatch depth vs. thatch mass, turfgrass color, turfgrass density, and NDVI, were analyzed by location.

Results and discussion

Thatch depth across genotypes and locations

NTEP. The NTEP trial revealed a significant cultivar by location interaction, indicating that genotypes responded differently across locations (Fig. 2). Statistical differences in thatch depth among genotypes

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Table 1. Site description for National Turfgrass Evaluation Program (NTEP) experimental trials conducted from 2019 to 2024 across six US locations, including planting dates, soil type and pH, fertilizer regimens, mowing heights, irrigation, and plug harvest dates.

Location	Latitude and longitude	Planting date	Soil type	Soil pH	Fertilizer applied	Mowing details	Irrigation details	Plug harvest date
Olathe, KS	38°52′53″N; 94°49′9″W	07/11/19	Silty clay loam	6.5	16–0–4 fertilizer (1 lb N/1000 ft^2): 1 May 2020, 26 May 2021, and 9 Jun 2023	Rotary mower: 1.5 inch Reel mower: 0.75 inch	0.75 inch applied weekly when rainfall was insufficient	05/14/24
Stillwater, OK	36° 07′19″N; 97° 06′14″W	07/01/19	Sandy clay loam	7.2	25–0–10 fertilizer (1 lb N/1000 ft^2): Aug 2019 (0.5 lb N/1000 ft^2): Apr, May, Aug, and Sep 2020, 2021, 2021, and 2023	Reel mower: 1.5 inch	Irrigation as needed to prevent wilting	06/13/24
West Lafayette, IN	44°59′22″N; 93°10′34″W	07/11/19	Silt loam	6.8	Urea fertilizer (46–0–0) 1 lb N/1000 ft^2 in 2019 and 2020 24–0–22 (0.75 lb N/1000 ft^2): 2021, 2022, and 2023	Rotary mower: 3 inch	Irrigated as needed to prevent wilting	06/18/24
Dallas, TX	32°59′13″N; 96°46′02″W	07/19/19	Silty clay	7.8	25–5–10 fertilizer (0.5 lb N/1000 ft^2): 18 Apr and 4 Jun 42–0–0 fertilizer (1.0 lb N/1000 ft^2) Sep 2020, 27 Apr 2021, and 21 Sep 2021 Urea fertilizer (1 lb N/1000 ft^2): 19 May, 22 Sep 2022, and 18 Apr 2023	Reel mower: 1.25 inch (2019–24)	Irrigated as needed to prevent wilting	05/15/24
Davie, FL	26°5′3.48″N; 80°14′17.88″W	11/4/19	Sand	7.5	4 lb N/1000 ft^2 annually (2019–24)	Reel mower: 0.58 inches, 2 to 3 times weekly	75% of ET applied through irrigation	01/16/24
Citra, FL	29°24′42″N; 82°6′35″W	Late Jun 2019	Sand	7.1	13–4–13 fertilizer (1.2 lb N/1000 ft^2 and 0.9 lb N/1000 ft^2): Mar and May 2020 and 2021, respectively 15–0–15 fertilizer (1 lb N/1000 ft^2): Mar/Apr 2022– Sep/Oct 2023	Mowed at 2.5 inches weekly	Irrigated when drought stress was detected	02/20/24

ET = Evapotranspiration.

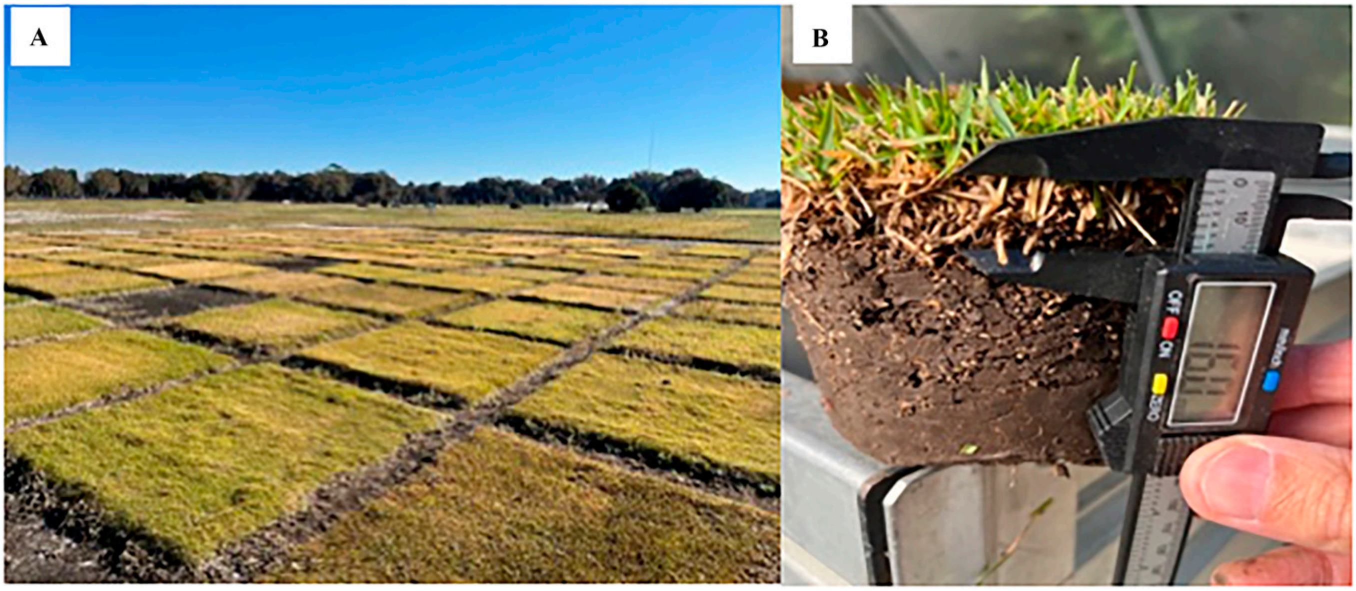

Fig. 1. Zoysiagrass on the National Turfgrass Evaluation Program (NTEP) trial in Citra, FL (A), and measurement of thatch depth with calipers (B).

were observed only in Dallas, where 'Emerald' (0.73 inch) had the highest thatch depth, and 'Meyer' (0.19 inch) and DALZ 1808 (0.27 inch) had the lowest thatch depth.

Although other locations did not show statistical differences, the range of thatch depth varied: Olathe: 0.59 inch ('Empire') to 0.81 inch (DALZ 1311); Stillwater: 0.13 inch (DALZ 1311) to 0.36 inch (DALZ 1808); West Lafayette: 0.71 inch (DALZ 1311) to 1.08 inch (DALZ 1701 and 'Emerald'); Davie: 0.29 inch (DALZ 1311) to 0.52 inch ('Emerald' and DALZ 1701); and Citra: 0.54 inch ('Emerald') to 1.21 inches (DALZ 1808). Higher thatch depths were observed in West Lafayette and Citra, where mowing heights were higher. Similarly, McFadden (2024) recently observed significantly greater thatch depth (0.70 inch) for Innovation mowed at 1.5 inches compared with 0.75 inch (0.57-inch thatch depth), highlighting the influence of mowing height and genotype by mowing interactions. Notably, McFadden (2024) reported a lower thatch depth for DALZ 1808 at both mowing heights. Shearman et al. (1980) also observed genotype differences in Kentucky bluegrass (*Poa pratensis* L.), where increasing mowing height (0.9–1.9 inch) significantly increased thatch accumulation (e.g., 0.19 inch for S-21 vs. 0.54 inch and 0.58 inch for 'Cheri' and 'Glade', respectively).

Kauffman et al. (2013) similarly demonstrated that aggressive growth habits influenced thatch accumulation, as observed in 'TifEagle' and 'Champion' bermudagrass (*Cynodon dactylon* × *Cynodon transvaalensis*), which accumulated deeper "thatch-mats" (1.06 inches and 1.09 inches, respectively) compared with 'SeaDwarf' seashore paspalum (*Paspalum vaginatum*) (0.88 inch) and 'Diamond' zoysiagrass (0.91 inch). These findings explain the role of genetic makeup in thatch accumulation, with denser, aggressive-growing genotypes generally exhibiting higher thatch levels.

USGA. In the USGA trial, no significant differences were observed in the thatch depth among genotypes in Kansas and Indiana. However, genotypic differences were significant in Florida, where DALZ 1701 (0.52 inch) exhibited the greatest thatch depth, while genotypes 6782-104 and 6785-19 had the shallowest depth (0.15 inch) (Fig. 3). Across locations, the range of thatch depth varied from 0.48 inch (DALZ 1808) to 0.73 inch (DALZ 1701) in Kansas, and from 0.64 inch (6844-150) to 0.82 inch (DALZ 1701) in Indiana.

These results suggest that environmental factors such as soil type, climate, and management practices may have influenced thatch accumulation in Kansas and Indiana more than genetic differences among cultivars. For example, the absence of genotypic differences in these locations aligns with studies by Kauffman et al. (2013), who linked thatch depth to factors such as reduced water infiltration and lower oxygen content in the soil. In addition, environmental conditions and management practices, including fertilization, irrigation, and mowing height, can significantly influence thatch depth (Carrow 2000; Horst et al. 1996). The complexity of genotype-by-environment interactions warrants further investigation into the relative contributions of these factors to thatch accumulation.

Correlation between thatch depth and morphological traits

For the NTEP and USGA trials, correlations were site-specific due to the variation in genotypes evaluated across locations.

NTEP. Correlations among thatch depth and turfgrass morphological traits are summarized in Table 3. Although several correlations were not significant, significant correlations were observed across multiple sites and are presented.

In Dallas, a significant negative correlation ($P < 0.0001$; $R^2 = 0.8217$) was observed between thatch depth and firmness, which illustrates that as thatch accumulates, surface firmness decreases (Fig. 4). Similar findings were reported by Beard (1973) and Carrow (2000), who

Table 2. Site description for United States Golf Association (USGA) experimental trials conducted from 2021 to 2024 across three US locations. Details include geographic coordinates, planting dates, soil type and pH, fertilizer regimens, mowing heights, irrigation, and plug harvest dates.

Location	Latitude and longitude	Planting date	Soil type	Soil pH	Fertilizer applied	Mowing details	Irrigation details	Plug harvest date
Kansas	38°52′53″ N; 94°49′9″W	06/17/21	Silty clay loam	6.5	16–0–4 fertilizer (0.75 lb N/1000 ft^2): 6 Jul 2021 (1.25 lbs. N/1000 ft^2) – 1 Jun 2022	Rotary mower: 1.5 inch Reel mower: 0.75 inch	0.75 inch applied weekly when rainfall was insufficient	05/14/24
Indiana	44°59′22″N; 93°10′34″W	07/21/21	Silt loam	6.8	6–24–24 fertilizer (0.44 lb P/1000 ft^2): Jul 2021 24–0–22 (1 lb N/1000 ft^2): 17 Aug 2021 and 24 May 2022 28–0–18 (0.75 lb N/1000 ft^2): 30 May and 1 Sep 2023 and 2024	1.75 inch–0.75 inch	Irrigated as needed to prevent wilting	07/05/24
Florida	29°24′42″N; 82°6′35″W	08/30/2021	Sand	7.1	15–0–15 fertilizer (1 lb N/1000 ft^2) – Oct 2021, Mar, Aug, and Oct 2022; Apr, May, Jul, and Sep 2023	Mowed at 0.75 inch 2 to 3 times weekly	Irrigation was applied only to prevent drought stress	02/04/24

noted that thicker thatch layers act as a buffer, reducing surface hardness by trapping moisture and organic matter. However, under sandy soil conditions, Stier et al. (2000) found that a light thatch layer (~0.2 inch) could enhance firmness. Notably, this correlation was site-specific and was not observed at other locations under the NTEP trial.

A significant positive correlation was observed between thatch depth and NDVI in Dallas (P = 0.0275; R^2 = 0.2099) and Citra (P = 0.0111; R^2 = 0.2942) (Fig. 5). NDVI, a common indicator of vegetation vigor, generally increases with denser and healthier plant coverage. Genotypes with high shoot density and quality, such as Zeon and Emerald, likely contributed to this trend. Bremer et al. (2011) and Beard and Rieke (1976) reported that NDVI responds to biomass accumulation and is positively associated with shoot density. In addition, higher thatch depth may indirectly boost NDVI by enhancing moisture retention, thereby supporting the vegetation. However, excessive thatch accumulation in high-performing cultivars may necessitate management strategies to prevent negative effects on turfgrass quality, such as reduced firmness or increased disease susceptibility.

In Stillwater (Fig. 6A), Dallas (Fig. 6B), and Davie (Fig. 6C), thatch depth had a significant positive correlation with tiller numbers among genotypes: Stillwater (P = 0.0382; R^2 = 0.1819), Dallas (P = 0.0142; R^2 = 0.2541), Davie (P = 0.0070; R^2 = 0.2871). The observed trend was likely driven by species derived from *Zoysia matrella*, which are characterized by high shoot density and prolific tillering, both of which contribute to thatch accumulation. Increased tillering leads to greater biomass production, which, in the absence of cultivation or thatch removal practices, contributes to thatch accumulation. However, no thatch removal or any form of cultivation practices were implemented during this study. These findings align with Trenholm et al. (1999), who reported that dense, tiller-rich stands were associated with increased thatch accumulation, particularly in well-fertilized and irrigated systems. Huang and Liu (2009) also demonstrated that tillering is positively correlated

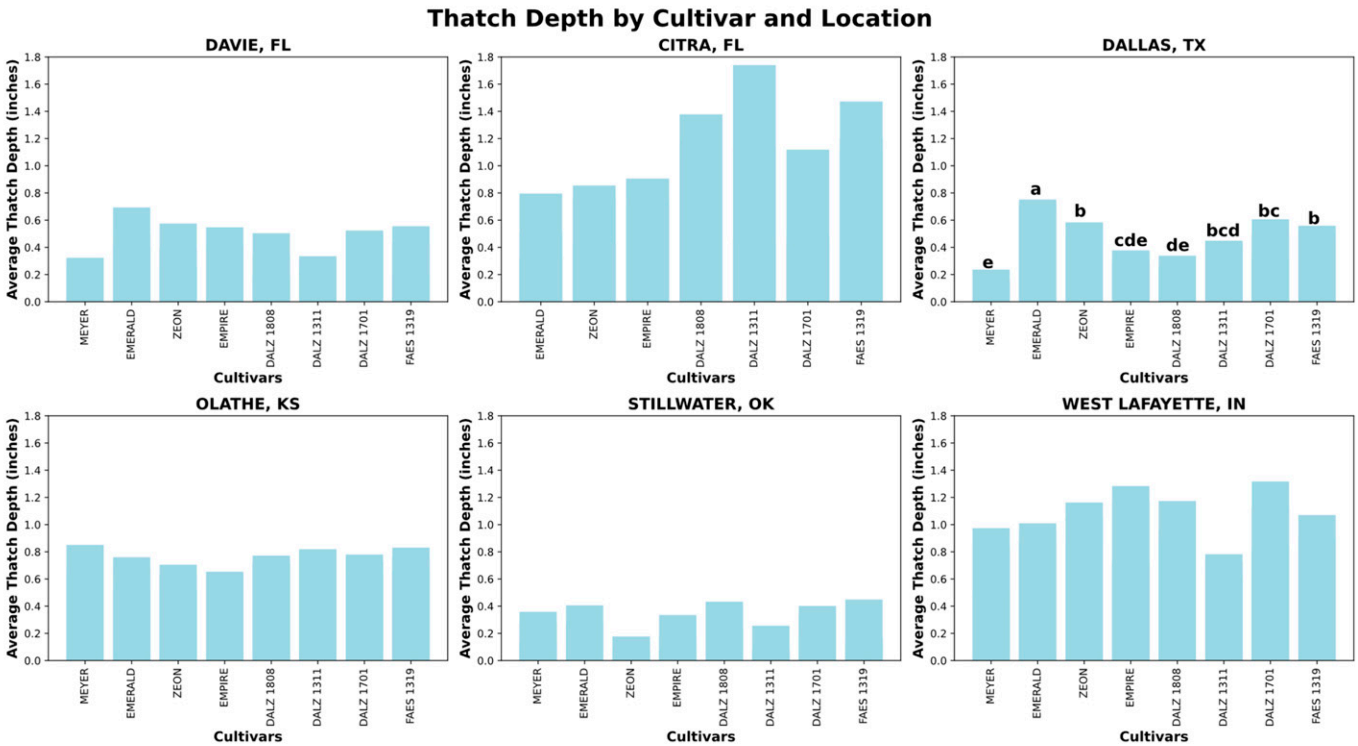

Fig. 2. Thatch depths among zoysiagrass genotypes in National Turfgrass Evaluation Program (NTEP) trial in Olathe, KS; Stillwater, OK; West Lafayette, IN; Dallas, TX; Davie, FL; and Citra, FL. Statistical differences among genotypes in Dallas, TX (P < 0.05).

with shoot density and biomass production in species such as Kentucky bluegrass and creeping bentgrass (*Agrostis stolonifera* L.).

In Stillwater (Table 3), a negative correlation between thatch depth and thatch mass was observed. One possible explanation for this is that the sandy clay loam at this site, coupled with management practices such as mowing height and irrigation frequency, may have favored thatch compaction rather than thatch mass accumulation. In addition, the relatively high soil pH (7.2) could have enhanced microbial decomposition of organic matter, reducing thatch mass while still allowing the structural depth of thatch layers to persist.

USGA. Table 4 summarizes the correlations among thatch depth, thatch mass, and turfgrass traits observed in the USGA trials. Although most relationships were not statistically significant, notable correlations are described as follows and presented in the corresponding figures.

In Kansas, thatch depth and thatch mass exhibited a significant positive correlation ($P = 0.001$; $R^2 = 0.3209$) (Fig. 7). This finding indicates that as the thatch layer deepens, the total organic material mass increases correspondingly. However, this relationship was not consistently observed across all locations in the trial.

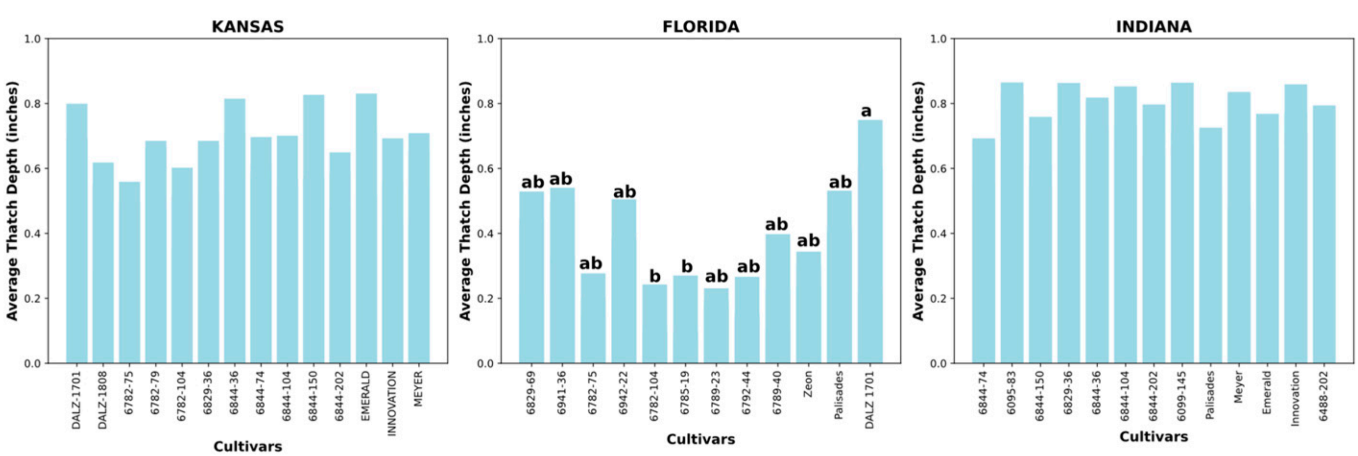

Fig. 3. Thatch depths among zoysiagrass genotypes in United States Golf Association (USGA) trials in Kansas, Indiana, and Florida. Statistical differences among genotypes occurred in Florida only (P < 0.05).

Table 3. Correlation coefficients between thatch depth (TD) and thatch mass (TM) vs. selected turfgrass morphological traits at six National Turfgrass Evaluation Program (NTEP) trial locations. Measurements were collected on the day of thatch collection in 2024.

Variable	Olathe	Stillwater	West Lafayette	Dallas	Davie	Citra
TD vs. Turfgrass Quality	NS	NS	NS	* (0.427)[i]	NS	NS
TD vs. Turfgrass Color	NS	NS	NS	NS	NS	NS
TD vs. Turfgrass Density	NS	NS	NS	** (0.55)	NS	NS
TD vs. Firmness	NS	NS	NS	*** (−0.906)	NS	NS
TD vs. NDVI	NS	NS	NS	* (0.458)	NS	* (0.542)
TD vs. Leaf Width	* (0.435)	NS	NS	** (−0.635)	NS	NS
TD vs. Tillers	NS	* (0.425)	NS	* (0.504)	** (0.536)	NS
TD vs. TM	NS	* (−0.406)	NS	NS	NS	NS
TD vs. Texture	NS	NS	NS	* (0.5)	NS	* (−0.509)

[i] Correlation coefficient values when significant.
NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001, respectively.

Beard (1973) reported that deeper thatch layers are associated with higher organic mass due to the cumulative deposition of plant material. Similarly, Turgeon (1977) found that thatch accumulation in perennial turfgrass systems is primarily driven by the continuous deposition and compaction of organic matter, leading to increased mass as depth increases. However, this study did not explicitly account for environmental factors, which may have influenced the observed correlation in Kansas.

In Indiana, thatch depth and NDVI exhibited a significant negative correlation (P = 0.0057; R^2 = 0.2038) (Fig. 8), contrasting with the positive correlation observed in Dallas and Citra during the NTEP trial. Excessive thatch accumulation hinders light, water, and nutrient movement to the root zone, thereby reducing photosynthetic activity and NDVI values (McCarty and Kerns 2005). Beard (1973) similarly reported that heavy thatch layers can weaken turfgrass stands due to limited access to essential resources. Furthermore, zoysiagrass cultivars in Indiana, such as ‘Emerald’ and ‘Empire’, are more susceptible to winter injury from freezing temperatures, potentially impacting NDVI values (Dunn and Diesburg 2004; Morris 2001; Patton and Reicher 2007). Fine-textured cultivars, which are less suited to the climatic conditions in Indiana may also exhibit lower NDVI values. Although environmental factors such as winter injury were not directly assessed in this study, they may have influenced the observed negative correlation.

In Citra, FL, thatch depth was negatively correlated with surface firmness (P = 0.0001; R^2 = 0.3600) (Fig. 9), consistent with findings from Dallas in the NTEP trial. In addition, in Citra, FL, leaf width was positively correlated with highest thatch depth ($P \leq$ 0.0001; R^2 = 0.4564) (Fig. 10). A similar trend was observed in Olathe in the NTEP trial (Table 3), whereas an inverse relationship was found in

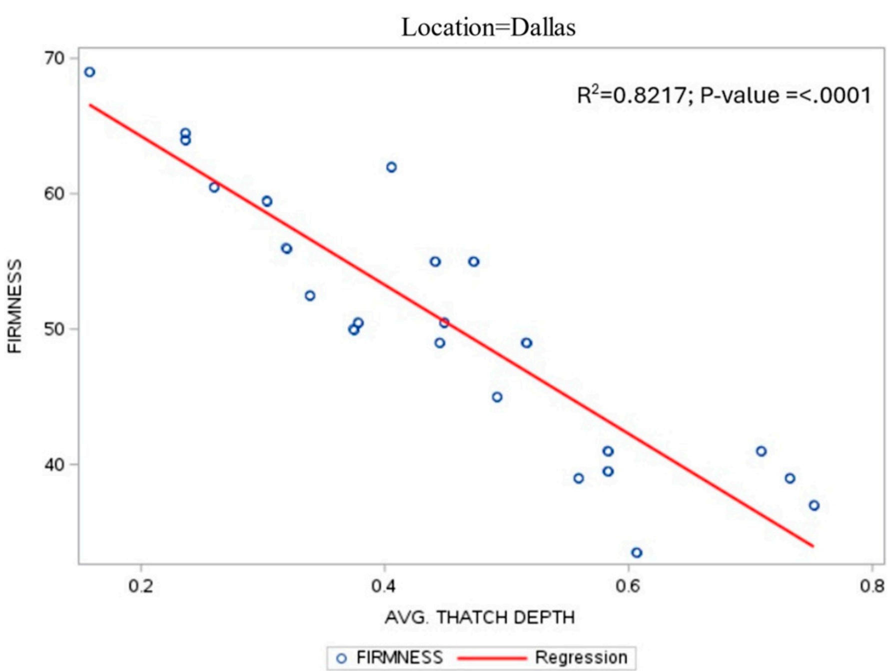

Fig. 4. Correlation between thatch depth (inches) and firmness (Clegg hammer measurement in surface units “gravities”), which measures the surface firmness (lower values softer firmness; higher values harder firmness) in the National Turfgrass Evaluation Program trial in Dallas (P < 0.0001). Firmness was measured once in May 2024.

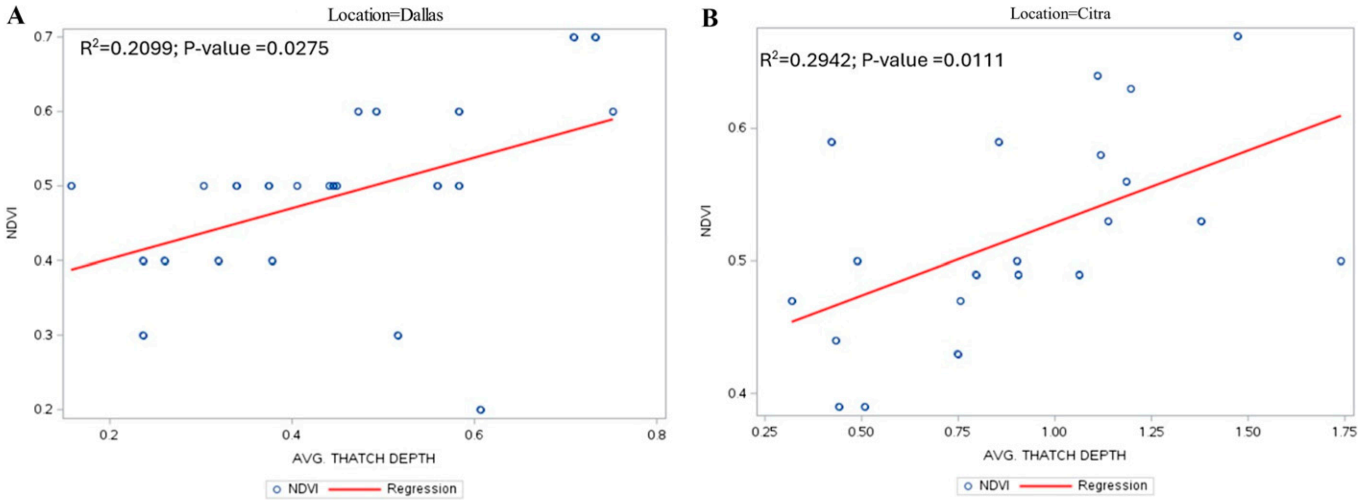

Fig. 5. Correlation between thatch depth (inches) and NDVI in the NTEP trial in (A) Dallas, TX, and (B) Citra, FL ($P < 0.03$). Thatch depth was measured in May 2024 in Dallas, TX, and Feb 2024 in Citra, FL.

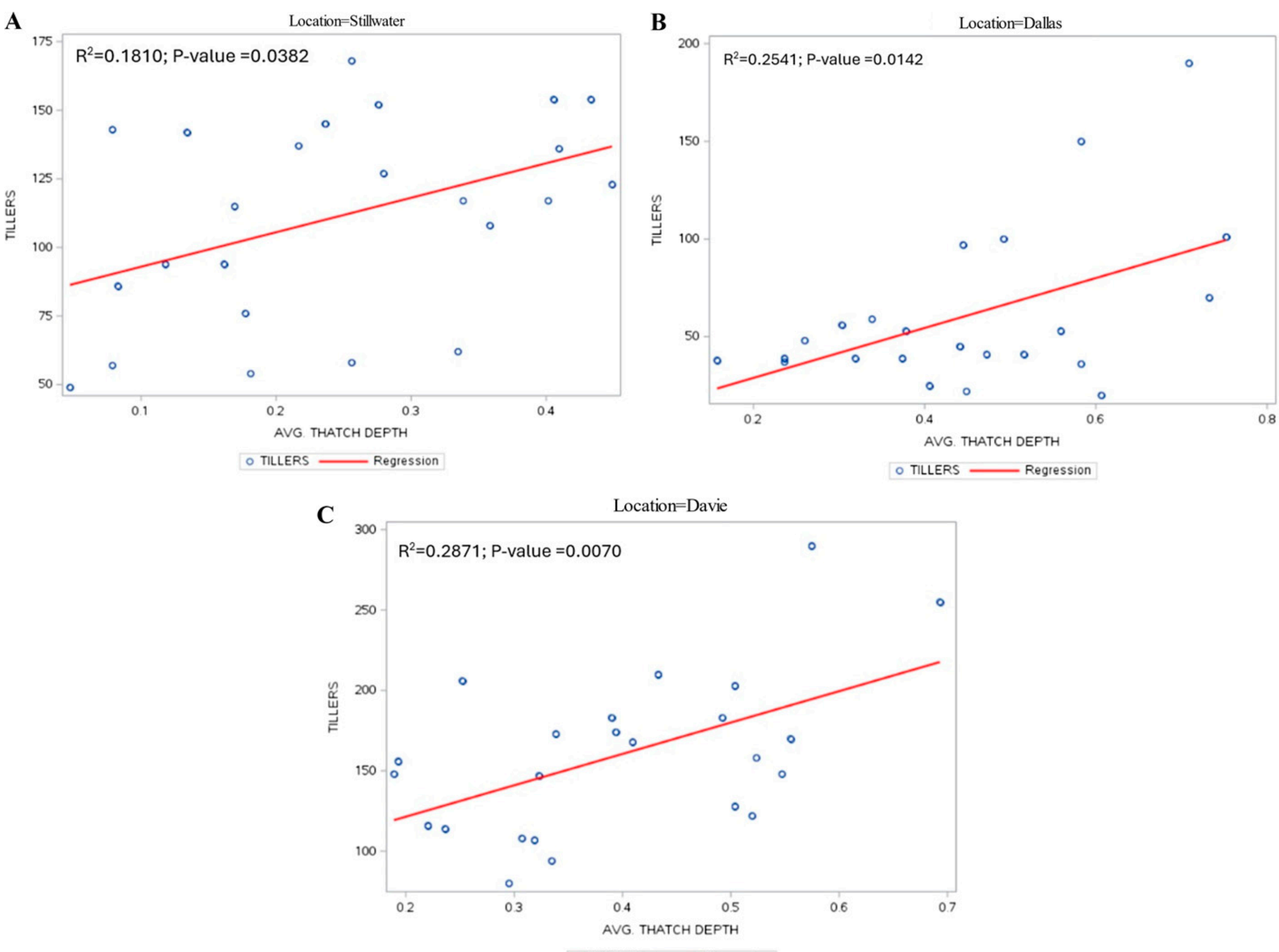

Fig. 6. Correlation between thatch depth (inches) and tiller number in the NTEP trial in (A) Stillwater ($P = 0.0382$), (B) Dallas ($P = 0.0142$), and (C) Davie ($P = 0.0070$). Tillers were measured by counting the number of shoots that emerged from the base of the turfgrass on each 4-inch diameter plug. Tiller numbers were counted from plugs sampled in Jun (Stillwater), May (Dallas), and Feb (Davie) 2024.

Table 4. **Correlation coefficients between thatch depth (TD) and selected turfgrass morphological traits across three US sites for the United States Golf Association (USGA). Morphological traits were collected on the day of thatch collection.**

TD vs. data	Kansas	Indiana	Florida
TD vs. Turfgrass Density	NS	NS	NS
TD vs. Firmness	NS	NS	*** (−0.599)[i]
TD vs. NDVI	NS	** (−0.451)	NS
TD vs. Leaf Width	NS	NS	*** (0.676)
TD vs. Texture	NS	NS	*** (−0.644)
TD vs. Tillers	NS	NS	* (−0.402)
TD vs. TM	*** (0.566)	NS	NS
TD vs. Turfgrass Color	* (0.353)	NS	NS
TD vs. Turfgrass Quality	* (0.338)	NS	NS

[i] Correlation coefficient values when significant.
NS, *, **, *** Nonsignificant or significant at $P \leq 0.05$, 0.01, or 0.001 respectively.

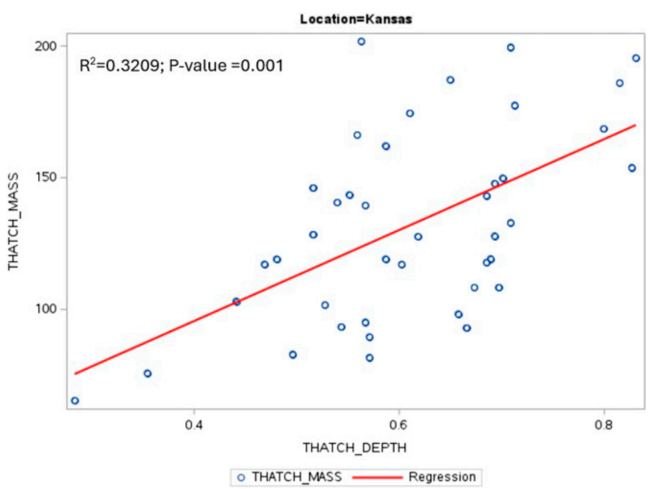

Fig. 7. Correlation between thatch depth (inch) and thatch mass (mg) in the USGA trial in Kansas (*P* = 0.001). Thatch depth and mass data were collected from plugs sampled in May 2024.

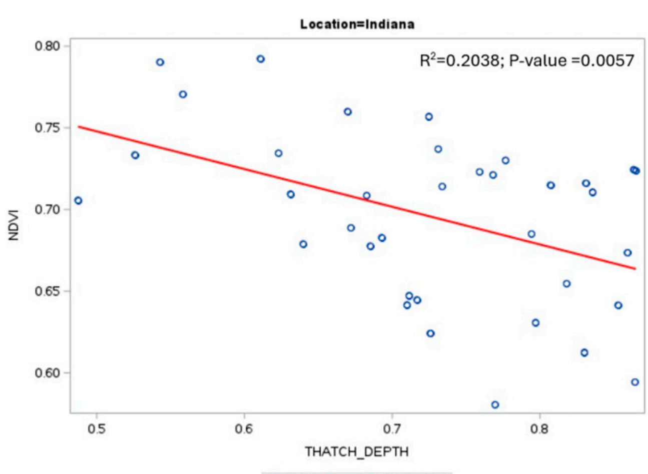

Fig. 8. Correlation between thatch depth (inch) and NDVI in the USGA trial in Indiana (*P* = 0.0057). NDVI measurements occurred in Jul 2024.

Dallas. These results suggest that as thatch depth increases, broader leaves may develop, possibly due to enhanced nutrient and moisture retention near the surface, making these resources more accessible to the turfgrass.

Conclusion

This study examined differences in thatch depth and its correlations with morphological traits among zoysiagrass genotypes across multiple environments in the NTEP and USGA trials. In the NTEP trial, significant differences in thatch depth among genotypes were observed only in Dallas, where 'Emerald' had the greatest thatch depth and 'Meyer' and DALZ 1808 had the lowest. Genotypes at West Lafayette and Citra exhibited greater thatch accumulation, likely due to increased mowing heights at these sites. In the USGA trial, significant genotype differences in thatch depth were observed only where DALZ 1701 accumulated the most thatch in Florida.

Variability in correlations between thatch depth and morphological traits across sites highlights the influence of both environmental and genotype-specific factors. Notably, thatch depth was negatively correlated with firmness in Dallas (NTEP) and Florida (USGA). Conversely, NDVI was positively correlated with thatch depth in Dallas and Citra in the NTEP trial but negatively correlated in Indiana in the USGA trial, suggesting site-specific interactions between environmental and genotype performance. The relationship between thatch depth and leaf width also varied by site, showing positive correlations in Citra and Olathe but no significant correlation in Dallas.

Overall, although significant differences in thatch accumulation among genotypes were location-specific, consistent correlations between thatch depth and morphological traits across multiple sites offer important insights into the genetic and environmental factors influencing thatch production in zoysiagrass. These findings emphasize the need for future research to investigate the causal relationships between thatch depth and turfgrass morphological traits.

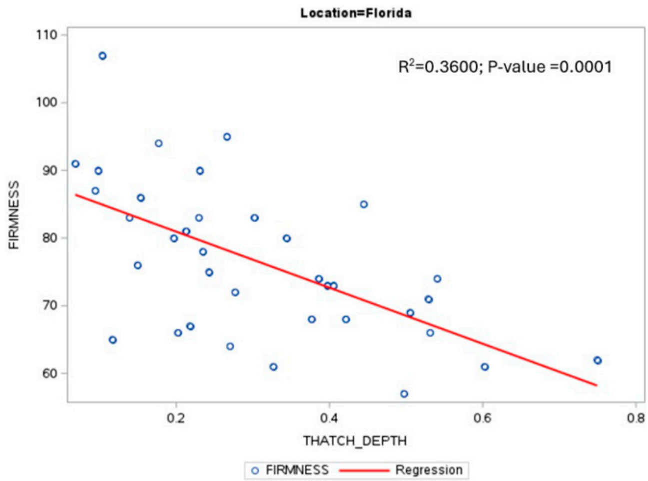

Fig. 9. Correlation between thatch depth (inch) and surface firmness (Clegg hammer measurement in surface unit "gravities") which measures the surface hardness (lower values softer firmness; higher values harder firmness) in the USGA trial in Florida (P = 0.0001). Firmness was measured once in Apr 2024.

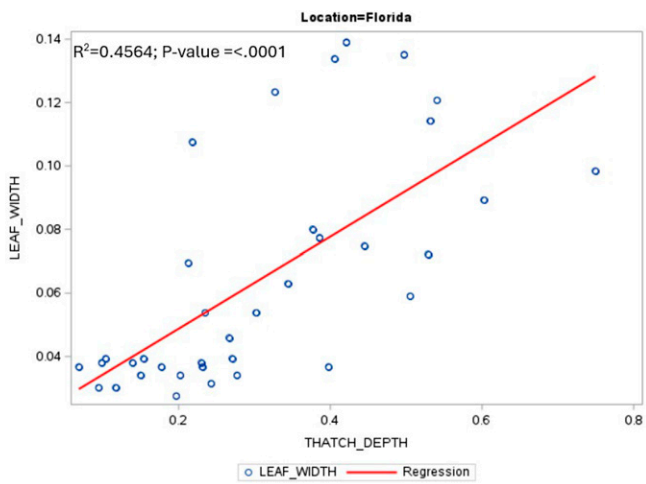

Fig. 10. Correlation between thatch depth (inch) and leaf width (inch) in the USGA trial in Florida (P < 0.0001). Data were collected on plugs removed in Apr 2024.

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