the fungus into the root, rather than just a colonization of the surface, and disruption of the plant vascular system (Figure 2).

Next we can transfer a portion of the root onto a glass slide and observe the hyphae under the high-powered compound microscope (Figure 3). Under certain conditions, different root pathogens can produce unique infection structures that may aid in diagnosis. But these structures are often not observed, and morphological differences between pathogenic fungi like *G. graminis* var *avenae* and non-pathogenic fungi like *P. graminicola* may be impossible to find.

Assuming we see all the above signs of a possible root-infecting disease, how can we differentiate between the major diseases mentioned above? Pythium root diseases are somewhat distinct from necrotic ring spot, summer patch, and take-all patch by the cooenocytic (non-septate) hyphae, oospores (sexual spores), and sporangia (asexual spore bearing structure) they produce. But both microscopically and macroscopically it is often very difficult to determine when a sample is take-all patch, NRS, or summer patch. One factor to take into account is the turfgrass species. Take-all patch will only infect creeping bentgrass (*Agrostis stolonifera*), and summer patch is most commonly observed on annual bluegrass (*Poa annua*), Kentucky bluegrass (*Poa pratensis*), perennial ryegrass (*Lolium perenne*), and fescues (*Festuca* spp.). Recent research by Dr. Lane Tredway at North Carolina State has shown evidence of summer patch infecting bentgrass, but more research is needed to determine that relationship (Tredway, 2006). Necrotic ring spot will only infect Kentucky bluegrass, perennial ryegrass, and the fescues while *P. graminicola* has been observed on most common turfgrass species.

If the turfgrass species offers few clues to identify the pathogen, the timing of symptom development can also provide insight. The causal agents of NRS and take-all patch infect when soil temperatures are between 55 and 65°F, yet symptoms develop anywhere from mid-May to late June depending on the weather conditions (Couch, 1995). The causal agent of summer patch becomes increasingly more aggressive as soil temperatures rise throughout the summer, so symptoms that first appear in August or September often are the result of summer patch. The timing method of diagnosing root diseases is where the experience factor comes in, and there are always exceptions to the rule. At this point in the process we can make a confident diagnosis as to the causal agent and will not proceed with further analysis unless there is significant doubt or a specific request has been made by the superintendent.

What more can be done to identify samples that fail to provide a clear cut diagnosis, or where the presence of *P. graminicola* may be suspected? When complications arise, or the superintendent wants proof of identity beyond the previously described methods, there are some further techniques that can be done. Any further analysis usually begins by culturing the pathogen in the lab (Figure 4), which begins by isolating the fungus on a sterile media and then re-isolating until a pure culture without any contaminants is obtained. There are some identifying characteristics of each culture, such as appearance and growth rate at different temperatures, but most often the culture will be used for polymerase chain reaction (PCR)-based analysis. PCR-

Figure 3: Using a compound microscope allows for the higher magnification of the hyphae on the root surface, which can provide further clues to the identity of the pathogen.

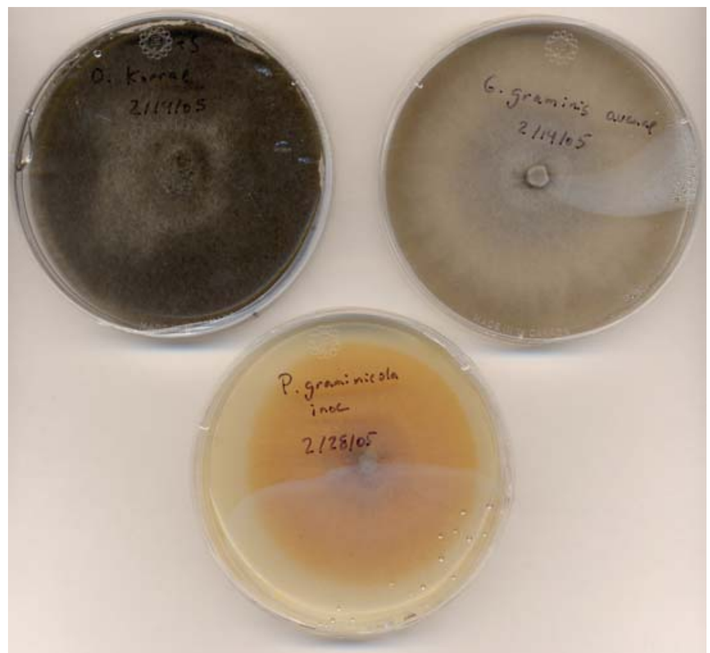

Figure 4: Though a similar appearance on the root, in culture these pathogens can appear very different. The causal agent of necrotic ring spot is in the upper left, for take-all is in the upper right, and the non-pathogenic Phialophora graminicola is on the bottom. Photo courtesy of Steve Abler of Reinders, Inc

based diagnostic methods are a species-specific molecular diagnostic method that provide a much more confidant diagnosis of fungal identity. Problems with these methods include time (culturing root pathogens can take weeks), cost, and the cross-reactivity of the species-specific nature of each PCR-based method (Tredway, 2006).

All turfgrass samples that come into the Turfgrass Diagnostic Lab are fully inspected to take into account all possible pathogenic and non-pathogenic causes alike. No pathogen operates in a vacuum, and root pathogens are no different. Environmental conditions, cultural practices, and colonization by non-pathogenic fungal species such as *P. graminicola* and the bacteria *Pseudomonas* spp. will all have an effect on the degree of symptoms observed (Landschoot et al, 1993). The mere presence of fungal hyphae on the roots or of darkened roots or basal regions does not necessarily indicate a root disease, and on the contrary just because at first glance the roots appear healthy does not rule out an infection.

This is where you as the submitter play a crucial role. Proper sample submission and completion of our sample submission form will aid us in providing the fastest and most accurate diagnosis of your sample. More details on sample submission as well as a link to download the sample submission form can be found at our website, www.plantpath.wisc.edu/tdl, which is currently being revamped to provide the maximum benefit to the turfgrass industry of Wisconsin and surrounding states.

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Lessons Learned from a Bold Experiment

By Dr. Wayne Kussow, *Emeritus Professor of Soil Science, University of Wisconsin-Madison*

BACKGROUND

In 1993 the UW turfgrass research team consisting of Drs. Koval, Kussow, Meyer and Rossi designed a long term study entitled "Turfgrass Management Systems". This was a bold venture because the design of the study was unconventional. Rather than take the classical approach of varying only one or two cultural practices while attempting to keep all other practices constant, in this study the suite of cultural practices making up the production system was constantly varied to achieve the ultimate goal of maintaining different putting green speeds on a sustained basis. In other words, the cultural practices employed were not fixed, but were those required to achieve a particular type of performance, that being putting green speed.

In the interest of making the outcomes of the experiment broadly applicable, the study included three different green speeds that served as the performance standards being sought, and was conducted on sand-based and pushup greens, each populated with three creeping bentgrass cultivars of different vintages and physical attributes. The target speeds were: (1) consistently > 10 feet; (2) around 9 feet; and (3) between 7 and 8 feet. The intent was to cover the full gambit from private clubs with very demanding members to daily fee public golf courses. The creeping bentgrass cultivars were 'Penncross', 'Providence' and the recently released 'Crenshaw'.

Another bold feature of the experiment is that it was designed to extend over several years. Very few agencies are willing to commit to funding a research project for more than two or three years. This study had an intended lifetime of 10 years broken into several phases. The phases were: (1) grow-in year; (2) 3 years of maturation; (3) 2 years of transition to *Poa annua* infested greens; and (4) a 4-year conversion back to bentgrass.

The final bold feature of this team effort was the assumption that the team would remain intact or replacement faculty would be hired on a timely basis. This didn't happen. Dr. Rossi departed for Cornell University, Dr. Koval retired, and Dr. Meyer left the university to start a family. It took up to two years to replace each of them and in some instances the replacements chose to pursue other avenues of research. Thus, Dr. Kussow reluctantly assumed responsibility for the project in 1996. Efforts to populate the greens with *Poa annua* in 1998 and 1999 were not successful and, with funding rapidly being depleted, the experiment was terminated in 2001 without the final two phases being implemented.

LESSONS LEARNED

There were positives and negatives with regard to the lessons learned in this bold study. As already noted, continuity in staffing and funding became serious issues. The project proved to be overly ambitious. Its execution required far more time, supplies and materials, equipment and manpower than anticipated. These are the negative lessons learned.

What follows are the main and presumably useful lessons learned in the study or, as the case maybe, lessons relearned. The format is a series of graphs based on what were literally hundreds of observations.

Lesson # 1: Putting green speed is determined primarily by mowing height. Over seven years the height of cut accounted for nearly 81 % of the differences measured in green speed (Fig. 1). Choice of creeping bentgrass cultivar and type of green construction rarely had a significant influence. The thought that the more upright growth habit of 'Crenshaw' would result in greater speeds than those of the more prostrate 'Penncross' proved not to be true.

Figure 1 is a useful guide when attempting to change putting greens speed through change in mowing height. But speed will vary significantly around the average value at any particular height of cut. Differences of 6 inches or more (those detectable by low handicap golfers) can occur on a day-today basis depending on time of day and weather. The typical situation is peaking of green speeds at about 1:00 (1300 hours) in the afternoon (Fig. 2). This presumably reflects morning drying and then the effect of turfgrass re-growth as the day progresses. But many times putting green speed just kept increasing through out the day, often gaining up to 8 inches between 9:00 am and 5:00 pm. The other factor affecting green speed is time of year. In every year of the study green speeds increased as the season progressed (Fig. 3) and the lower the height of cut the greater the shift in speed. What caused this was not apparent in the study.

Lesson #2: The most effective way to temporarily increase speed is double cutting, but only if the speed is already at 9 feet or more (Fig. 4). Rolling the greens or mowing when the surface was dry rather than wet did increase speed, but the increases were quite variable and often not significant (> 0.5 foot) from the golfer's perspective.

Lesson # 3: Application of Primo may or may not significantly increase putting green speed. In this study, where Primo was applied monthly at 0.24 oz/M, the season-long effect on green speed was nearly always insignificant regardless of bentgrass cultivar or type of green construction (Fig.5). Rather, the effect of Primo on green speed depended on time of season (Fig. 6). In this example, speed increases when Primo was applied in August were consistently significant (above 0.5-foot) while none of the speed increases in June were significant. Note that in both months the increases in green speed achieved with Primo application were greatest at the lowest mowing height.

Lesson # 4: Mowing height definitely influences putting green quality visually rated by observing turfgrass density, stand uniformity, erectness, and amount of grain. Quality did not vary significantly among the

Figure 1

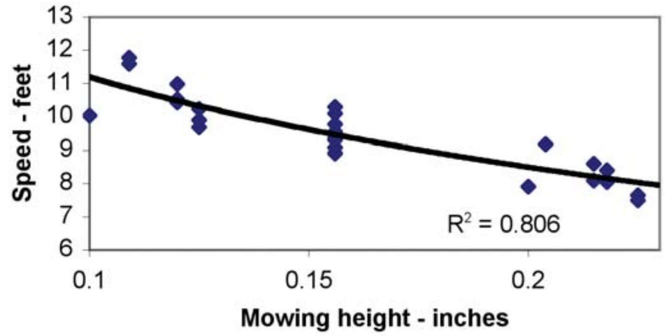


Figure 2

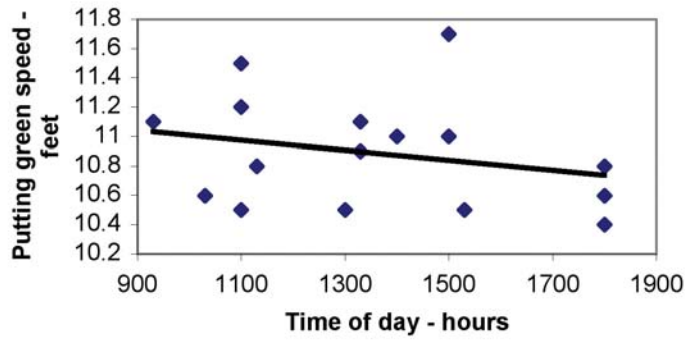
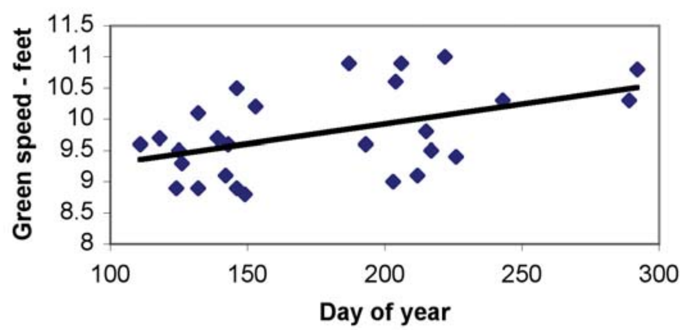


Figure 3



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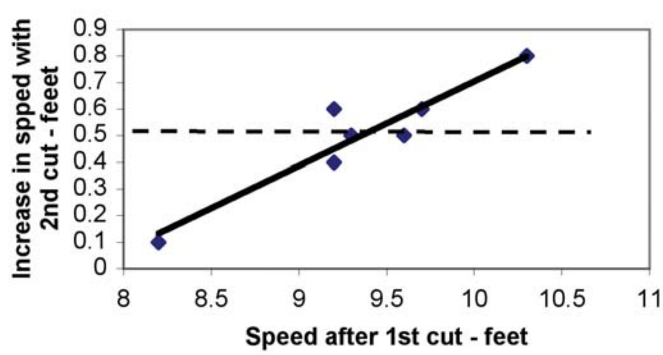
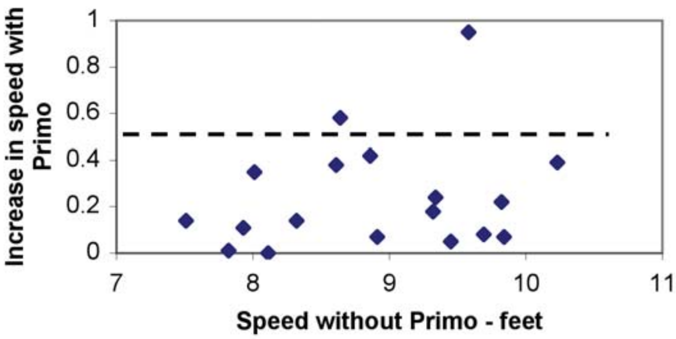


Figure 5



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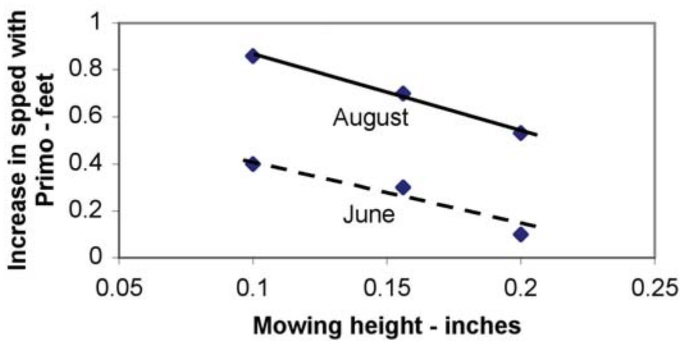
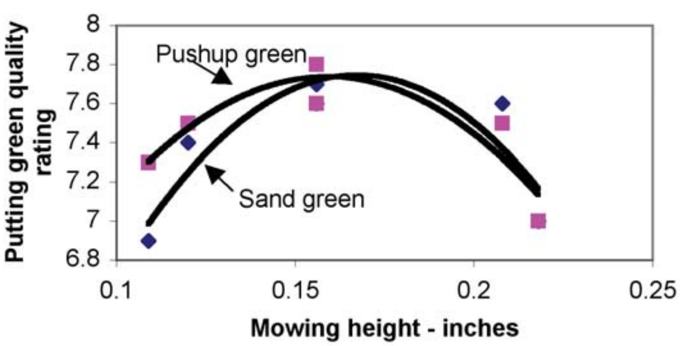


Figure 7



three bentgrass cultivars. At the lowest height of cut the pushup green averaged higher quality ratings than did the sand green (Fig. 7). This difference arose primarily because the pushup green maintained consistently higher turf density. Putting green quality attained a maximum at the 0.156-inch height of cut and there was no longer a difference between the pushup and sand greens. Declines in quality at greater mowing heights were due more prostate growth and extensive grain development.

Lesson # 5: Putting green traffic tolerance increases with increasing mowing height and decreases with the amount of traffic (Fig. 8). These are not surprising results. Studies with various grass species maintained under different cultural practices have almost invariably shown that traffic tolerance relates primarily to verdure, the amount of live plant material remaining after mowing. As seen in figure 8, whether or not mowing height significantly alters traffic tolerance depends on the amount of traffic imposed. When traffic was equivalent to only 12,000 rounds of golf, both increases in mowing height (0.125 to 0.156-inch and 0.156 to 0.2-inch) significantly increased traffic tolerance.

With 23,000 rounds, traffic tolerance increased significantly only when the change in height of cut was from 0.125 to 0.2-inch. Applying the equivalent of 30,000 rounds of golf reduced traffic tolerance to very low levels and the effect of mowing height was no longer significant. Rather, traffic tolerance was extremely low at all mowing heights.

Lesson # 6: Creeping bentgrass growth is influenced much more by mowing height than cultivar or type of green construction. Several counts of tiller numbers showed that on the sand green those numbers consistently increased with increases in mowing height (Fig. 9). On the pushup green tiller numbers increased when mowing height was increased from around 0.1 to 0.156-inch, but not when further increased to around 0.2-inch.

Mowing height affected root density (Fig. 10), but

Figure 8

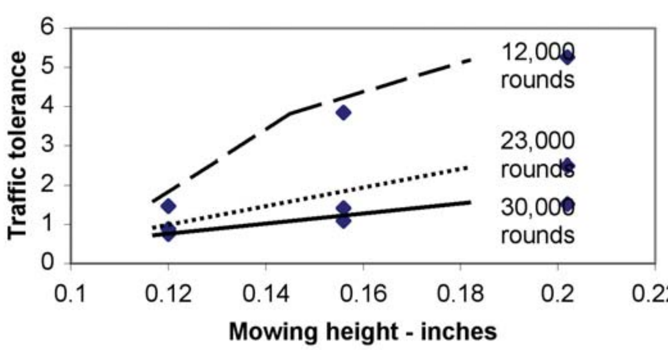
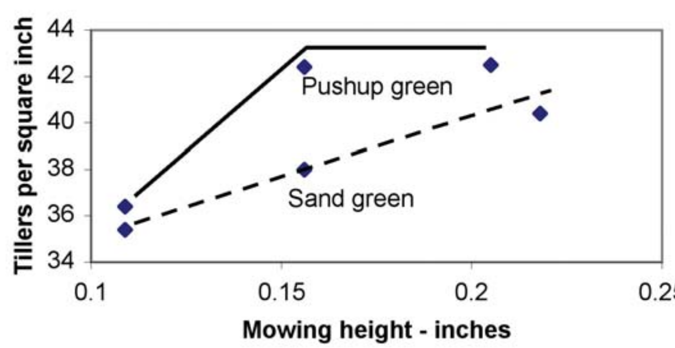


Figure 9



not rooting depth (Fig. 11). Both were consistently greater in the pushup than the sand green. In fact, rooting depth in the pushup green averaged twice that of the 4-inch depth in the sand green. Root density, the weight of roots per unit soil volume to a 6-inch soil depth, linearly increased with increased height of cut. When going from a mowing height of around 0.1 to 0.2-inch, root density increased 54% in the sand green and 38% in the pushup green. Differences among the bentgrass cultivars in root density and depth were not significant.

Lesson # 7: Mowing height has secondary effects on putting green quality. The two secondary effects observed were the extent of infection by dollar spot and of invasion of the greens by algae. Dollar spot infection rates were always higher in the pushup green and in both greens increased with height of cut (Fig 12). Algae began to invade the greens in 1997, the second year during which the target green speeds were being consistently achieved. Mowing at 0.109 to 0.125-inch resulted in algae invasion of 25% area of the sand greens and 50% of the pushup green areas (Fig.13). Merely increasing the mowing height to 0.156-inch reduced the area of algae invasion to 2% or less. At no time during the course of the study did algae invade greens mowed at 0.2-inch or higher.

Extents of dollar spot infection and algae invasion were strongly related to tiller numbers, a measure of turfgrass stand density. Across all mowing heights tiller numbers accounted for 94% of the differences in numbers of dollar spot infections per plot (Fig. 14). The most likely explanation for this relationship is the dual effects of mowing height and tiller numbers on the amount of leaf surface area available for infection. With tiller numbers increasing with mowing height (Fig.9), the relationship between tiller numbers and algae invasion (Fig. 15) was almost identical to the relationship between algae invasion and mowing height (Fig. 13). The implication here is that in going the lowest to the highest height of cut, the increases in turf density eventually led to shading of the soil surface to the extent where algae could no longer survive.

The secondary effects of mowing height, bentgrass cultivar and type of green construction on soil analyses were also observed. Changes in soil pH and soil test P and K were tracked over a 47 month period. The changes observed bore no relationship to mowing height or bentgrass cultivar grown, but understandably differed with type of putting green construction.

Soil pH slowly declined in the calcareous sand green and rose in the acid pushup green (Fig. 16). Both greens appear to have been approaching a common pH of around 7.3. This suggests achievement of a chemical equilibrium that reflects the 8.3 pH and ion content of the irrigation water, the types and quantities of fertil-

Figure 10

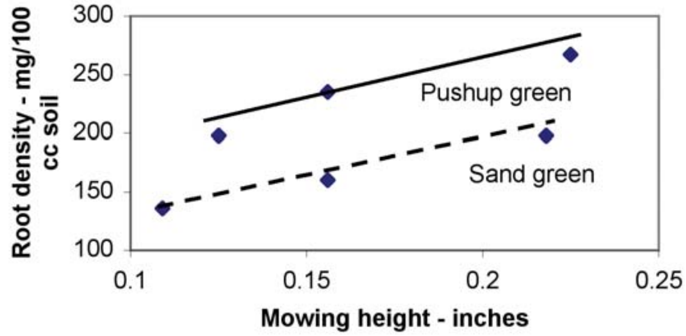


Figure 11

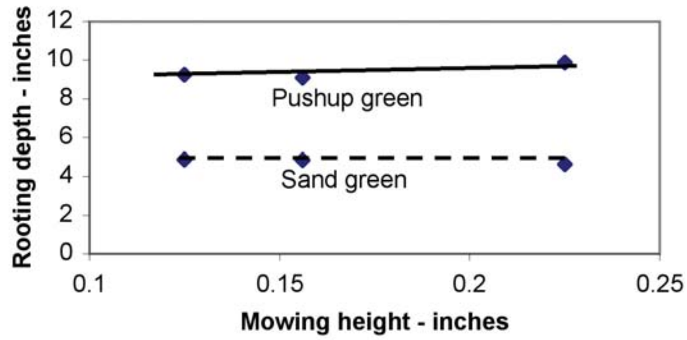


Figure 12

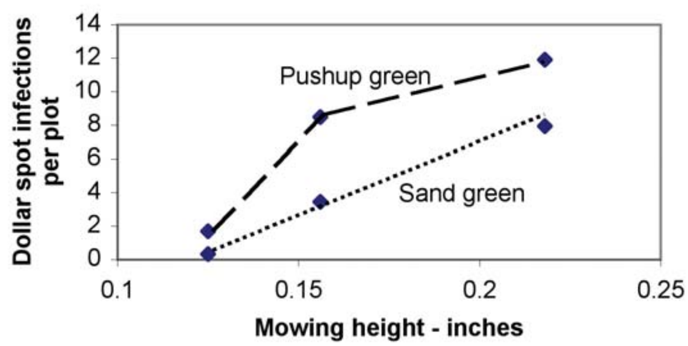
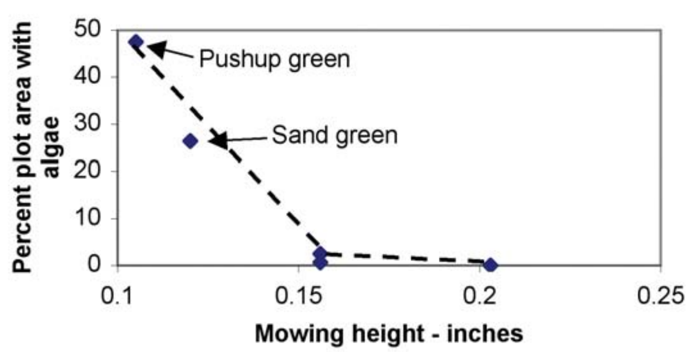


Figure 13



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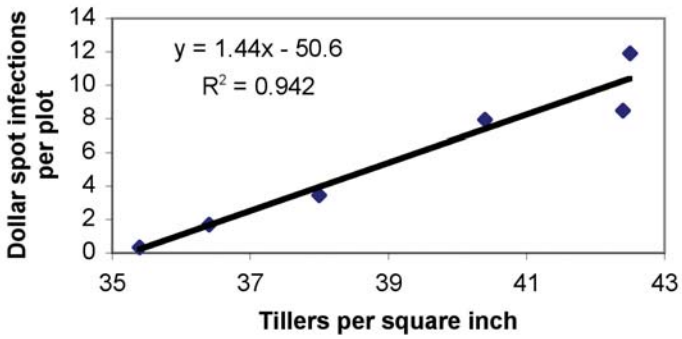


Figure 15

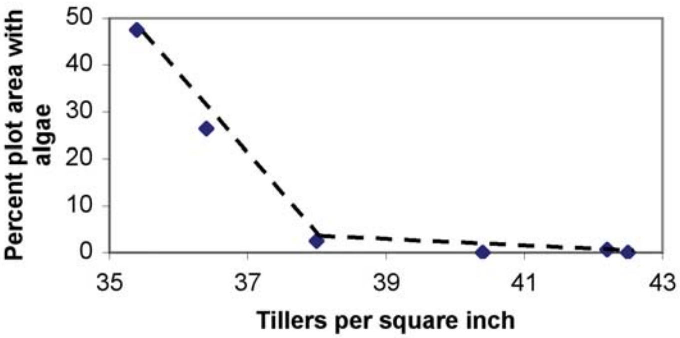


Figure 16

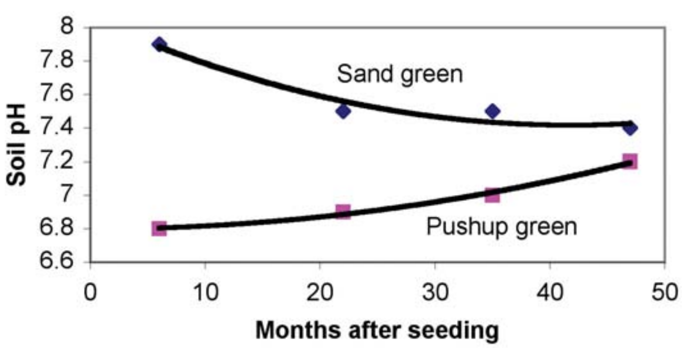
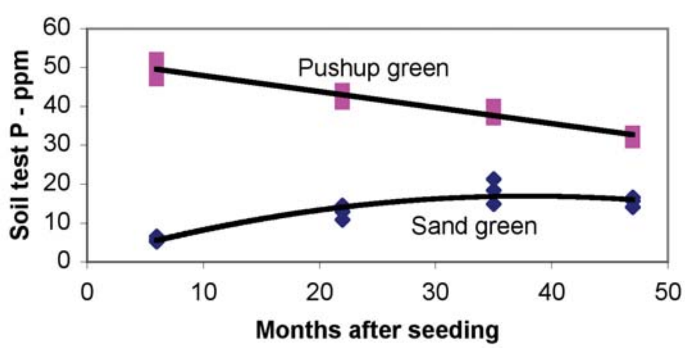


Figure 17



izers applied, and nutrient leaching and clipping removal rates.

Tabulation of all fertilizer applied between 1994 and 2001 showed an annual N rate that averaged 3.2 lb/M on the sand green and 3.1 lb/M on the pushup green. Of particular interest are the ratios of N, P_2O_5 and K_2O applied because it is turfgrass growth response to N that drives plant uptake of P and K. The ratios of P_2O_5 to N applied were nearly identical at 0.25 to 0.26 lb P_2O_5 per pound of N for the two putting greens. At this ratio, soil test P in the sand green rose from a minimally adequate 4 ppm initially to 12 ppm at 20 months and then stabilized at about 15 ppm (Fig. 17). This signifies that in the sand green the maintenance application rate of P was 0.25 lb P_2O_5 per pound of N.

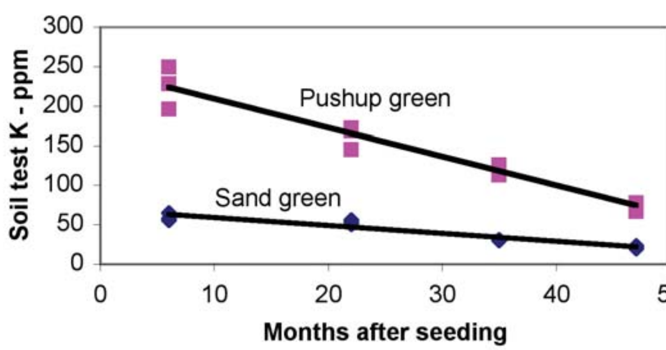
While soil test P on the pushup green was never inadequate for a putting green, the 0.26 lb P_2O_5 applied per lb N was not sufficient to maintain soil P at a reasonably constant level. This might be expected in view of the fact that native soil P buffering capacities are far less those of sand-based greens.

The ratios of K_2O to N applied averaged 0.74 lb K_2O/lb N on the sand green and 0.66 on pushup green. Neither prevented declines in soil test K (Fig. 18). Other research conducted at the Noer Facility has indicated that for sand greens the maintenance rate of K is more like 1.0 lb K_2O/lb N.

SUMMARY

This 8 year study confirmed that first and foremost, mowing height determines putting green speed. For the bentgrass cultivars 'Pencross', 'Providence' and 'Crenshaw', the cultivar grown had little to no influence on speed. In fact, 'Pencross' provided slightly higher speeds than did the more upright growing 'Crenshaw". With a frequent sand topdressing program in place, putting green speeds generally did not differ with type of construction (sand-based or pushup). Mowing at 0.109 to 0.125-inch maintained putting green speeds at > 10 feet and they occasionally approached 12 feet. Mowing at 0.156-inch resulted in speeds quite consis-

Figure 18



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