Overseeded TifEagle Bermudagrass Putting Greens: Effects of Nitrogen (N) Rate and Traffic

by

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ABSTRACT

Hybrid bermudagrass (*Cynodon dactylon x C. transvaalensis* Burtt-Davy) putting greens are often overseeded with a cool season species at the onset of fall dormancy. Intended to provide winter color for the putting surface and added protection from traffic, many new generation ultradwarf putting greens are overseeded with the smaller seeded grass *Poa trivialis* (L). However, little is known about the impact of winter play management on the overseed, and the subsequent bermudagrass as it emerges from dormancy in the spring. Thus, the objective of this research was to examine the combined effects of overseeding, traffic and N rate on the performance of a hybrid bermudagrass ('TifEagle') putting green that had been overseeded with *Poa trivialis*.

The two-year study was conducted at the Auburn University Turfgrass Research Unit, with N rate and overseed treatments arranged in a factorial design of 4 N rates (0, 0.5, 1 and 2 g N m^{-2}) and overseeding (yes or no). These plots were all split in traffic (yes or no), which was applied twice weekly via a traffic simulator. Collected data included color, quality, shoot density, clipping yield, N content of clippings, total non-structural carbohydrates, and golf ball roll via stimpmeter.

In general, plots needed the highest N rate of 2 g N m^{-2} $month^{-1}$ for best color and quality. Traffic had the greatest effect on turf quality, and the presence of the overseed did not provide any further improvement in turf quality, either for the overseed or the bermudagrass. The presence of the overseed did affect bermudagrass shoot density, with significantly fewer bermudagrass shoots measured during the transition period. In conclusion, the presence of the

overseed negatively affected the bermudagrass, and other options for the provision of winter color (such as painting) should be considered.

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INTRODUCTION

Ultradwarf bermudagrass [*Cynodon dactylon* (L.) Pers x *C. transvaalensis* Burtt-Davy] greens are gaining appreciation in the southern United States from both turf managers and golfers alike because of their improved playability traits compared to their hybrid predecessors, and their inherent adaptation to the climate. As a warm-season grass, bermudagrass goes dormant during the winter months and the subsequent loss of green color is not appreciated by golfers. The most common practice used to provide attractive and playable greens during the winter has been to overseed the greens in the fall, (sow a cool-season grass directly into the bermudagrass canopy), generally with perennial ryegrass (*Lolium perenne* L.), rough bluegrass (*Poa trivialis* L.), or a mixture of the two (Dudeck and McCarty, 1989). Potential benefits of overseeding include a uniform playing surface, less thinning of dormant turf from equipment and foot traffic, and less weed invasion during winter dormancy (Mazur and Wagner, 1987). However, since the underlying bermudagrass is the predominant turfgrass and will be the playing surface for the majority of the year, additional research to understand the effects that overseeding, subsequent fertilizing of the overseed, and foot traffic, has on the bermudagrass is needed. This research is designed to study the long standing practice of overseeding dormant bermudagrass greens, to better understand any positive or negative effects associated with the practice.

Golf courses in the transition zone and south have long sought to identify suitable grasses for their putting surfaces that match the quality of creeping bentgrass [*Agrostis stolonifera* var. *palustris* (Huds.) Farw.] greens used in the North, but survive the high temperatures of the South. The first viable and most widely used hybrid bermudagrass was 'Tifgreen' (Hein, 1961), followed by 'Tifdwarf' being extensively used until the introduction of the ultradwarf cultivars in the 1990s (Guertal and Evans, 2006). These bermudagrass cultivars provide a quality putting surface, but are not without a few shortcomings that result in golfer complaints. Issues include: a higher mowing height as compared to bentgrass, resulting in slower ball speed, presence of 'grain' or tendency to grow in one direction, which has significant effect on ball roll (McCarty et al., 2011), and the development of off-types or segregated patches within each green resulting in a mottled look to the putting surface (Caetano-Anolles, 1998). Tifdwarf also takes on a noticeable purple hue in the fall that can be objectionable to some (Burton, 1966).

With the boom of golf course construction in the 80s and 90s and subsequent demand for high quality greens, the use of bentgrass beyond its typical region led to advances in heat-tolerant cultivars (Xu and Huang, 2001). This decade saw the release of more heat tolerant and disease resistant cultivars of bentgrass, including Crenshaw and the Penn A and G series (Landry and Schlossberg, 2001). Courses throughout the country switched to these new cultivars with the promise of outstanding year-round greens quality. In the transition zone and deeper south, bentgrass greens were soon synonymous with quality golf courses. With these new bentgrass options, golf courses in the Southeast could typically have high quality greens conditions for 9-10 months of each year, the trouble coming in the summer months, when the bentgrass is prone to summer bentgrass decline (SBD)(Bunnell et al., 2002; Murphy and Rieke, 1994).

Despite these issues, compared to Tifdwarf, bentgrass is typically viewed as the principal grass for high quality putting greens in the transition zone (McCarty et al., 2011).

As a cool season grass, bentgrass' optimum growing temperature range is broadly ranged from 15-24 degrees C (Beard, 1973). More recent research found the growth and physiological activities of creeping bentgrass roots and shoots declined when exposed to root-zone temperatures of at least 23 C for 54 days (Pote et al., 2006), or 30 C for 20 days (Huang and Gao, 2000). In the southeast, the daytime and nighttime temperatures are often above this recommended range from late spring to early fall (Xu and Huang, 2001). The result is stressed turf that is more susceptible to disease, as well as damage from traffic (Bunnell et al., 2002). Bentgrass management in the Southeast requires intensive use of water, fungicides, fans and sand based greens (Guertal et al., 2005; Jordan et al., 2003). Beyond these non-disruptive steps, frequent light verticuting, aerating and topdressing is required to maintain adequate air and water movement in the soil (Huang, et al. 1998; McCarty et al., 2007). Additional maintenance practices may include high-pressure water injection (Murphy and Rieke, 1994), and use of wetting agents (Tucker et al., 1990). Regardless of these inputs, southeastern bentgrass greens can still become highly stressed and 'thin' in areas, resulting in poor turf quality for golf in the summer (Guertal et al., 2005). In the worst cases, greens are closed to play and temporary greens are used in the fairway, or a course can be closed altogether until greens conditions improve. Not surprisingly, some golf course managers grew tired of the large maintenance budgets associated with bentgrass greens, in addition to the poor playing conditions during the summer months, and were interested in alternatives.

In the late 90s, a second generation of 'ultradwarf' bermudagrasses were developed and released specifically for golf greens (Hanna and Elsner, 1999). The grasses are notable because they have significantly narrower leaves (Roche and Loch, 2005), higher shoot densities, better turf quality, and the ability to withstand lower mowing heights than Tifdwarf (McCarty et al., 2011). These characteristics produce a denser surface, which provide greater ball roll distances, better surface uniformity and more consistent ball roll than traditional varieties (Hollingsworth et al., 2005; McCarty et al., 2011). Naturally suited to the southeastern environment, these new cultivars were rapidly planted on southern putting greens, and continue to be a favorite for newly constructed or renovated bermudagrass putting greens (Guertal and Evans, 2006; Hollingsworth, 2005). Although these new cultivars do have improved putting quality, turf managers are still learning how to manage their unique issues such as proper fertilizer management, thatch control, root growth, and winter survival (Goatley et al., 2005; de los Reyes, 2001;McCarty et al., 2011).

OVERSEEDING OF DORMANT BERMUDAGRASS

In many regions that grow hybrid bermudagrass, the fairways, putting greens and athletic fields are overseeded in the fall with perennial ryegrass or roughstalk bluegrass (*Poa trivialis* L.) to provide green color, a uniform playing surface and tolerance to wear during the period of bermudagrass dormancy (Dudeck and McCarty, 1989; Green et al, 2004; Mazur and Rice, 1999; Horgan and Yelverton, 2001). For ultradwarf greens, rough bluegrass produces the best overseed turf quality (Anderson and Dudeck, 1994) when seeded during the fall. The use of *Poa trivialis* for overseeding ultradwarf bermudagrass putting greens does not require special preparation before seeding, such as verticuting or scalping to open up the turf canopy (Hollingsworth et al, 2005). In that study, no relation was found between shoot density of the bermudagrass and subsequent shoot density of the *P. trivialis*. Additionally, spring transition of the overseeded hybrid bermudagrass green was not affected by fall-applied treatments or cultivation (Green et al, 2004; Hollingsworth et al. 2005).

Seeding rates vary widely in golf and athletic field operations, depending on type of seed used and the intended use of the overseeded area. In the turfgrass industry, some believe that lower seeding rates are best to reduce costs and allow more rapid transition to bermudagrass in the spring (Nutter, 1973). A study by Mazur and Rice (1999) examined various rates of perennial ryegrass for overseeding bermudagrass greens, and they discovered that seeding rate was a compromise between overseed turf quality and a smooth early spring transition back to bermudagrass. They found that turf quality of the overseed increased linearly with increased seeding rate, as did turf density as measured by leaf number. This was a function of higher seeding rates linearly decreasing leaf width and tillers per plant, suggesting higher putting quality (Mazur and Rice, 1999). Using high seeding rates also helps promote overseed to grow densely and upright, which should increase the wear tolerance of the actively growing grass stand (Deaton and Williams, 2010; Haselbauer et al., 2010).

The management of overseeding is unique because one species is only desired for a portion of the year, and grown in the same space as another, which is needed year-round. Horgan and Yelverton (2001) studied cultural methods to remove perennial ryegrass from bermudagrass, and noted that bermudagrass shoot density was consistently higher in non-overseeded plots, illustrating negative impacts of perennial ryegrass competition on bermudagrass growth. Other work has shown that cultivars of hybrid bermudagrass with dense shoot growth received little benefit from overseeding, as measured by turf quality after traffic events (Deaton and Williams, 2010). Less dense cultivars did exhibit better wear tolerance and quality when overseeded and exposed to traffic stress (Deaton and Williams, 2010). Ultradwarf bermudagrasses are characterized by a high shoot density (Hanna and Elsner, 1999; McCarty et al., 2011).

TRAFFIC

Traffic is an abiotic stress that can impose two forms of injury on turf: wear and soil compaction (Carrow and Petrovic, 1992; Trenholm et al., 2000). Wear injury of shoots is manifested by abrasion, tearing, or stripping of the leaf tissue, resulting in chlorophyll degradation and subsequent reduction in photosynthesis (Trenholm et al., 2000). Soil compaction, a consolidation of underlying soil, can cause reduced root growth, reduced water circulation and drainage within the soil, decreased soil oxygen levels, and reduce photosynthesis (Agnew and Carrow, 1985; Unger and Kaspar, 1994; Dest et al, 2009; Trenholm et al., 2000). Recent studies have quantified traffic stress on cool-season turf, finding that 90% of injury is associated with wear, with the remaining injury due to compaction (Dest et al., 2009). Much of the prior research related to traffic wear and compaction tolerance in turfgrass has revolved around athletic field and golf course fairway usage, with little focusing on ultradwarf bermudagrass putting greens. Turfgrasses in high traffic venues are generally selected for tolerance to traffic or for an ability to quickly outgrow the injury (Trenholm et al., 2000). Furthermore, rates of recovery vary based on inherent growth rate of the grass species, and degree of severity of the injury (Hoffman et al., 2010b.).

In general, warm-season grasses (C_4) are more wear tolerant than cool-season (C_3) grasses (Lulli et al., 2012; Shearman and Beard, 1975). In a study comparing physiological and morphological factors and their influence on wear resistance in C_3 and C_4 plants, it was found that stolon and rhizome lignin content were the factors most associated with wear resistance

(Lulli et al., 2012). It was also noted that stolon and rhizome starch and rhizome glucose content were negatively correlated with wear resistance, but positively correlated with turfgrass recovery (Lulli et al., 2012). Factors that enhanced wear tolerance generally differed among species (Lulli et al., 2012; Sun and Liddle, 1993a), and also within species (Brosnan and Deputy, 2009; Dest et al., 2009; Trenholm et al., 2000). Hybrid bermudagrasses with greater traffic tolerance have finer textured leaves and more flexible stems (Sun and Liddle, 1993b), more prostrate leaf orientation (Brosnan et al., 2005), higher density (Trenholm et al., 2000), and greater lignin concentration in stolons and rhizomes (Lulli et al., 2012). In addition, although it has been reported that amount of verdure tissue does not influence wear tolerance (Shearman and Beard, 1975), it is generally recognized that greater shoot density reduces wear injury (Younger 1961; Sun and Liddle, 1993b).

In a study comparing seashore paspalum (*Paspalum vaginatum* Swartz.) to hybrid bermudagrass, Trenholm et al. (2000) found that the factors that improved bermudagrass wear tolerance included higher tissue rigidity from leaf lignin and leaf stem lignocellulose. Also, a dense turf canopy, and adequate stem moisture helped to maintain turgor pressure and possibly prevented stem breakage (Trenholm et al., 2000). It was also found that lignin was associated with secondary cell wall formation and thickening (Trenholm et al., 2000), and lignin content was positively associated with tissue age (Akin, 1989; Jung, 1989).

Similar traits in cool-season grasses like *P. trivialis* also relate to better wear tolerance. These include cultivars with high shoot density, flexible cell walls, and compactly arranged cells (Haan et al., 2009). *Poa trivialis* has become the overseeding grass of choice for bermudagrass putting greens (Johnson, 1994). However, this is the only setting where *Poa trivialis* is preferred to other cool-season options such as perennial ryegrass or Kentucky bluegrass (*Poa pratensis L.*)

for wear tolerance, as field tests at higher mowing heights have ranked *Poa trivialis* as the least wear tolerant species (Shearman and Beard, 1975).

Thoms et al. (2011) examined bermudagrass traffic tolerance as affected by perennial ryegrass on athletic fields and found that plots overseeded with perennial ryegrass had more thatch accumulation than non-overseeded plots. Also, hydraulic conductivity (K_{sat}) was greater in overseeded plots than non-overseeded plots. It was hypothesized that overseeding protected the bermudagrass from traffic damage during the fall, preventing leaf tissue and thatch from being removed. In addition, green cover from the overseeded dormant bermudagrass canopy served to protect from soil compaction, allowing for increased K_{sat} (Thoms et al., 2011). This study confirmed earlier work by Dunn et al. (1994) that showed that traffic decreased thatch and verdure compared to non-trafficked plots. Some thatch-mat layering is important to the resiliency of turf, although too much is generally detrimental to turfgrass management as it can reduce K_{sat}, pesticide efficacy, and promote anaerobic conditions that cause turfgrass quality to decline (McCarty et al., 2007).

Leaves of fine textured cultivars are arranged in a more vertical orientation than medium and coarse textured cultivars. In trials with Kentucky bluegrass cultivars offering improved traffic tolerance exhibited a more upright, vertical leaf orientation (Brosnan and Deputy, 2009). The same effect has been observed in bermudagrass, with Haselbauer et al. (2012), finding that both ‘Tifway’ and ‘Celebration’ bermudagrass cultivars were more traffic tolerant than ‘Patriot’ due to Patriot’s more horizontal leaf orientation. Similarly, turf density is an important factor for wear tolerance, as a study on athletic fields comparing hybrid bermudagrass cultivars found Tifway and ‘Riviera’ showed less damage to traffic than more open, less dense cultivars, regardless of being overseeded or not (Deaton and Williams, 2010).

Turfgrass recovery from traffic wear and compaction is species specific, and is correlated with growth rate and the number of meristematic growing points from which new growth develops (Hoffman et al., 2010a; Hoffman et al., 2010b). Specific agronomic practices such as fertilization and irrigation can influence turfgrass recovery (Canaway, 1985), as does the season in which the wear occurs (Park et al., 2010). Fertilization should be done carefully, since excess N and subsequent growth can lead to excess thatch accumulation (McCarty et al., 2011). Wear injury to the canopy of the biomass of a grass stand continues to occur until a critical point when soil is exposed (Minner and Valverde, 2005). In a traffic study on Kentucky bluegrass, increased traffic volume decreased turf quality and thatch thickness, and increased surface hardness (Minner and Valverde, 2005). Traffic stress also accelerated compaction stress when minimal mat and exposed wet soil conditions prevailed. Additionally, dispersed traffic stress (performed every other day compared to once a week for concentrated traffic) caused more long-term severe injury when compared to concentrated traffic stress (Minner and Valverde, 2005).

In a study with perennial ryegrass, Sills and Carrow (1983) found that visual quality, clipping yield, N use per unit area, evapotranspiration, and root growth declined with compaction. Verdure, total nonstructural carbohydrates (TNC), and percent N in leaf tissue were not affected by compaction. Initial TNC levels, water use efficiency, and N used per unit area increased as N rate increased. Clipping yield, N use per area unit, and water use efficiency were higher with a water-soluble N carrier. However, the most detrimental effects of compaction were on root weight and distribution at the high N rate. This study found that application of high N did not compensate for the adverse effects of compaction (Sills and Carrow, 1983).

Brosnan and Deputy (2009) suggested that differences in turf recovery could also be related to the ability of a cultivar to grow in compacted soil. Main effects of soil compaction were reduced verdure and individual shoot weight, while visual quality remained unaffected and shoot density tended to increase (Wiecko et al., 1993). Carrow et al. (1980) also found increased shoot density under compaction, likely due to tiller initiation as a function of higher ethylene levels in the compacted soils. While shoot density tended to increase, individual shoot size diminished. Also, less verdure, smaller shoot size and reduced clipping growth enhanced potential for wear stress on compacted turf (Wiecko et al., 1993).

Proper fertilization will aid in turfgrass traffic stress recovery (Canaway, 1985). Nitrogen was the single most important nutrient affecting wear tolerance and recovery (Bowman, 2003; Hoffman et al., 2010a). Other nutrients and their effect on wear tolerance have also been studied, including potassium (K). Trenholm et al. (2000) concluded that both bermudagrass and seashore paspalum had enhanced wear tolerance due high levels of K, as it increased turgidity and reduced tissue succulence. Potassium rates of 270-360 kg K ha^{-1} were also found to significantly improve wear tolerance in creeping bentgrass (Shearman and Beard, 1975). However, although it increased wear tolerance, Carrow et al. (1987) found no improved recovery ability in bermudagrass to coring and verticuting from applications of potassium.

NITROGEN

Nitrogen (N) is the mineral nutrient applied in greatest quantity to turfgrasses (Bowman et al., 2002; Hoffman et al., 2010a). When maintained at sufficient levels, N produces turf that is attractive, healthy, and able to recover from environmental and biotic stresses (Bowman et al., 2002). Turf fertilization contributes greatly to turf color, density, uniformity, and growth rate (Bowman, 2003; Hollingsworth et al., 2005). High levels of fertilizer and chemical inputs are usually required to maintain standards under high traffic stress, though alternative species are continually evaluated to reduce these inputs (Trenholm et al. 2000). Managers of ultradwarf putting greens prefer to use lower rates of N, in an effort to not encourage the excess thatch development to which the ultradwarfs are prone (McCullough et al., 2006). Several previous studies utilizing TifEagle bermudagrass used an applied N range of 30 to 36 g N $m^{-2}yr^{-1}$ to simulate golf course conditions (Stiegler et al., 2011a; McCullough et al., 2006; Hollingsworth et al., 2005). There are several forms of N available to turf managers in soluble and granular forms (Bowman, 2003; Hollingsworth et al., 2005). Quality of overseed and thatch depth was not affected by N source (Hollingsworth et al., 2005). Results from Hollingsworth et al. (2005) showed *P. trivialis* color was affected by the main effect of N source, and that the overseed was often greener when soluble N was applied.

In an N and K study, results showed that N was the single most important nutrient affecting wear tolerance and recovery (Hoffman et al., 2010b). It was determined that higher N rates did speed recovery, but rates of 343 kg ha^{-1} and above caused significant reductions in wear tolerance (Hoffman et al., 2010b). Bowman (2003) stated an annual rate of 200 to 250 kg N ha^{-1} was typical for perennial ryegrass. He also found that root biomass, length, shoot and tiller weights declined with increasing N rates, in contrast to shoot biomass N, which increased substantially with N rate (Bowman, 2003). Further research found that the optimum N rate for wear tolerance and recovery in perennial ryegrass was 245 kg ha^{-1} per year (Hoffman et al., 2010a). In an overseed trial on bermudagrass greens, the rate used for *P. trivialis* was 24.4 kg N ha^{-1} per month from November through April (Anderson and Dudeck, 1994). Similar results have been observed in bermudagrass, and when N rate increased, dry weight of stolons and rhizomes linearly decreased (Guertal and Hicks, 2009), or were reduced in the combined dry weight of stolons, rhizomes and roots (Guertal and Evans, 2006). McCullough et al. (2006) found carbohydrate levels were reduced when N rate increased.

Fertility programs are designed to moderate the supply of N to the turf and maintain growth at submaximal levels (Bowman, 2003). Fast-release sources of N, such as soluble urea, are readily available and rapidly absorbed by N-deficient turf (Bowman and Paul, 1990, Stiegler et al., 2011b). Leaf growth and color respond quickly to this periodic availability of N, but the response is often short-lived because the applied N is quickly exhausted (Bowman, 2003). In his study comparing daily versus periodic N application, Bowman (2003) concluded that fairly large pulses of N, supplied weekly to monthly, caused wide fluctuations in growth and tissue N pools, but had little or no effect on long-term productivity, and N use efficiency compared with daily addition at the same total rate. Although N did reach leaf tissue shortly after being applied, it could take several days for it to stimulate growth and have full value in the plant, in particular with turf mowed frequently (Bowman, 2003). Older putting greens can contain significant N, which has been sequestered in the soil OM from prior fertilizer applications (Kerek et al., 2003). This mineralization represents a more consistent source of N than that from periodic applications of soluble, quick release N fertilizers, and could diminish the fluctuations related to periodic N application (Bowman, 2003).

Use of foliar fertilization methods has been promoted as one possible way for turfgrass managers to produce improve turfgrass quality with fewer inputs (Liu et al., 2008). Soluble urea treatments made directly over the top of plant canopy should negate the possibility of denitrification and/or leaching loss, as these are related to soil/rootzone interactions (Stiegler et al., 2011b). The high density plant community, created by the low mowing heights of putting green turfgrass culture, is a very receptive environment for foliar absorption of urea (Stiegler et al., 2011b). This is supported by earlier research that found up to 57% of the urea fertilizer applied was recovered in leaves and shoots as early as 1 hour after application (Steigler et al. 2011a). The ability of plant leaves to absorb N (as urea) shortly after foliar fertilization application also has the capacity to limit NH_3 volatilization since urea hydrolysis would take place inside the plant rather than on the leaf surface (Wittwer et al., 1963). Immobilization of urea by leaf surface microbes is another factor that could minimize volatile N loss as NH_3 (Bowman and Paul, 1990). Furthermore, light irrigation to move urea fertilizer into the rootzone has been shown to mitigate NH_3 volatilization (Bowman and Paul, 1992; Knight et al., 2007).

For a non-overseeded bermudagrass green, an appropriate fertilization schedule would provide potassium and nitrogen into the fall, through the cold acclimation period, and stop once the bermudagrass goes dormant (Munshaw et al., 2006). A fertilizer ratio of 4-1-6 was found to produce superior cold tolerance for bermudagrass (Gilbert and Davis, 1971). Despite older notions on proper N management for bermudagrass winter hardiness, late season applications of N do not affect the freeze tolerance of bermudagrass rhizomes, and actually increased fall and spring color compared to the non-treated control (Goatley et al. 1998; Munshaw et al., 2006; Richardson, 2002). These studies however, did not fertilize the dormant bermudagrass, which does occur when fertilizing overseed throughout the winter (Hollingsworth et al., 2005). Schmidt and Shoulders (1972) found that excessive nitrogen fertilization in winter, especially on heavily thatched areas, reduced winter turf coverage. This is in contrast to findings by Hollingsworth et al. (2005), which found that N source did not affect shoot density of dormant bermudagrass.

Limited research exists related to seasonal effects on foliar N uptake efficiency by turfgrasses, in particular during a dormancy period. Stiegler et al. (2011a) studied foliar N uptake on bentgrass and ultradwarf bermudagrass putting greens, but only from May through September, and did not find significant differences in N uptake by month for the bermudagrass in the first year. However, they note in the first (May) application of the second year, lower absorption was observed in the bermudagrass, and attribute this to the semi-dormant state of turfgrass (Stiegler et al., 2011a). Mild winters in the Southeast can result in similar semi-dormant states of bermudagrass putting greens. Reduction in growth and N uptake by bermudagrass when progressing into dormancy approximately doubled N losses when applied late-season, lost primarily to leaching and volatilization regardless of the rate used (Picchioni and Quiroga-Garza, 1999). However, with overseeding, the cool-season seedling will be actively growing, and thus utilize excess N applied (Anderson and Dudeck, 1994).

SPRING AND FALL TRANSITION

When bermudagrass is dormant in the winter, it is still respiring, and survives on carbohydrates and other photosynthates accumulated during the previous growing season (Horgan and Yelverton, 2001). Shading from the actively growing overseed can extend dormancy of bermudagrass in the spring (Horgan and Yelverton, 2001). Ideally, the transition to overseed in the fall and back to bermudagrass in the spring should be a gradual one, so that the population of the overseed is not reduced faster than the bermudagrass can initiate new growth (Johnson, 1994). If the overseed is removed too early, the bermudagrass will require time to grow and replace it because it has not yet entered an actively growing state. If the overseed survives too long, the bermudagrass will be repressed during its initial spring growth period (Horgan and Yelverton, 2001; Mazur and Rice, 1999; McCauley et al., 2009). This occurs because the *P. trivialis* competes for space above and below ground, in addition to light, water and nutrients (McCauley et al., 2009). It also effectively shades out the underlying bermudagrass and hinders its ability to get the energy it needs to break dormancy (Liu et al., 2007). With high seeding rates needed to provide a quality putting surface through the winter, the overseed thrives in the cooler climate and takes up a significant amount of space once occupied by the bermudagrass (Hutto et al., 2008).

Cultural practices such as verticutting and scalping do not hasten overseed disappearance in the spring and early summer (Green et al. 2004; Horgan and Yelverton, 2001). As such, herbicidal transition with products like *Foramsulfuron* (Revolver) and *Rimsulfuron* (Tranxit) are commonly used today to aid in transition (Hutto et al., 2008; McCauley et al., 2009). Even with an herbicidal transition, it can be difficult to appropriately time the removal of the overseed and still provide an acceptable playing surface (Hutto et al., 2008; McCauley et al., 2009).

Bermudagrass regrowth and greenup from dormancy usually occurs when temperatures reach at least 15.5°C during the day and stay above 4.5°C at night (Stanford et al., 2005; Younger, 1959). Extended dormancy due to a long winter can result in carbohydrate depletion and death of bermudagrass stolons and rhizomes, also known as winter kill (Anderson et al., 2003; Richardson, 2002). Cold hardiness levels are not static in dormant plants, and maximum cold hardiness occurs in the early winter with bermudagrass, but declines during late winter (Davis and Gilbert, 1970; Dunn and Nelson, 1974). Carbohydrate levels, in the form of starch, were found to increase by 27% in stolons in early winter, while rhizome levels did not change, suggesting that stolons were the more important storage organ of carbohydrates made during the cold acclimation (Dunn and Nelson, 1974). In the same study, they found that stolons appeared to be more important sources of energy for respiration during late winter. Underground rhizomes receive some insulation from the surrounding soil while stolons growing at or near the soil surface are more susceptible to freezing and thawing stresses. Furthermore, stolons may be more elevated when thatch accumulates at the soil surface and thus less insulated by the soil and more exposed to cold air (Dunn and Nelson, 1974). Less severe winter kill was observed where bermudagrass utilized stored carbohydrates and greened early (Dunn et al., 1980). However, low carbohydrate reserves in late winter could result in an inability of plants to reharden in response to low temperatures following a warming period (Smith, 1964).

Susceptibility to winter injury has limited the use of bermudagrass to a few hardy cultivars in the transition zone (Dunn and Nelson, 1974; Chalmers and Schmidt, 1979). Ultradwarf bermudagrass has been found to be cold tolerant to temperatures of -5 to -6 C, with TifEagle being the most cold hardy of the group (Anderson et al., 2002). As winter nears, the plant goes through a cold acclimation period, and there is an increase in the (unsaturated/saturated) ratio of fatty acids (Samala et al., 1998), sucrose and other simple sugars accumulate, as does proline and glycine betain, which have been reported to help stabilize membranes and maintain water balance within the cell (Holmstrom et al., 2000). Plant membranes must be kept in a fluid state to maintain function, to the extent that when less fluid, or in a gel-like state, protein components become impaired or nonfunctional (Samala et al., 1998). Proline may have many functions in stress tolerance, including protein and membrane stabilization, and osmotic adjustment (Rudolph et al., 1986). Proline levels have been shown to increase during cold acclimation, decrease during de-acclimation and increase to a greater extent in cold-hardy species (Levitt, 1980). At the cellular level, freezing stress has a large dehydrative component due to the formation of extracellular ice (Chen et al., 1995). By increasing solute concentration, cell osmotic potential is decreased, making water movement out of the cell less likely, thus prevent the enlargement of ice crystals, and maintaining cell hydration (Rossi, 1997).

A study by Munshaw et al. (2006) found that cultivars that were known to be cold tolerant produced higher levels of linolenic acid and proline during fall and winter months. There were significant correlations between levels of linolenic acid and proline and regrowth after freezing. It was also noted that proline and lipid unsaturation were genetically controlled, and only affected by the environment and not by late-season inputs of N, or Fe. As such, it was concluded that it was prudent to use cultivars that were more cold hardy for a specific region, and less affected by stress during winter dormancy (Munshaw et al., 2006).

Current turfgrass management strategies often include the use of trinexapac-ethyl (TE) for a variety of reasons, including its ability to reduce the dormancy period of bermudagrass by extending fall color and promoting earlier spring green up (Fagerness et al., 2002; Richardson, 2002). This is thought to reduce winter injury, as Chalmers and Schmidt (1979) found that the freeze tolerance of bermudagrass rhizomes decreased as the post freeze dormancy period increased. Richardson (2002) found that using late-season N and TE reduced the dormancy period of bermudagrass by 20 to 25 days, and enhanced rhizome survival by 10 to 15%. However, it was also noted that earlier spring green up did predispose the turf to damage from a late season frost (Richardson, 2002).

ALTERNATIVES TO OVERSEEDING

Turfgrass managers with bermudagrass putting greens are abandoning the practice of overseeding and are instead painting the turf and/or using covers to protect the turfgrass, and shortening the dormancy period. The use of temporary covers presents a viable option to the practice of winter overseeding (Goatley et al., 2005). Common turf covers are light-weight, spun-bonded polyester, generally deployed when freezing temperatures are expected, and removed to allow play when temperatures are above freezing. Painting is typically done in conjunction with the use of covers, because although covers effectively shorten the dormancy period, aesthetically pleasing color is still required throughout winter months (Shearman et al., 2005; Liu et al., 2007). This cultural shift is becoming more common because paints and colorants are improving, it is less expensive than overseeding, and can provide a very playable surface (Liu et al., 2007). In order to provide protection from weather extremes on non-overseeded greens, covers are used and have been found to significantly enhance the winter survivability of bermudagrass grown in the transition zone (Shashikumar and Nus, 1993).

The primary reason for covering bermudagrass turf is protection from potentially lethal low temperatures (Goately et al., 2005). In northern climates, permanent covers are sometimes installed for the duration of the winter, but the mild winters of the southern United States warrant year-round usage of the turf and therefore require the use of temporary covers (Goatley et al., 2005). Other positive influences of covers that enhance winter survivability have been studied, such as increased crown moisture (Shashikumar and Nus, 1993), and reduced desiccation injury and increased root growth (Roberts, 1986). There has been some concern that enhancing or extending bermudagrass growth periods in the fall and winter may be a precursor to increased winterkill (Goatley et al., 1998; Richardson, 2002), but this has been proved incorrect (Goatley et al., 2005). The use of covers when temperatures were ≤4 C extended desirable bermudagrass quality for 5 to 8 weeks after the average fall killing frost date in Mississippi, and resulted in 4 to 6 weeks earlier greenup in the spring (Goatley et al., 2005).

Total nonstructural carbohydrate (TNC) levels in bermudagrass are reported to increase in the fall during cold acclimation (Dunn and Nelson, 1974). However, this process is not influenced by late-season N or Fe applications (Goatley et al., 2005). Goatley et al. (2005) found that the use of covers on bermudagrass generally increased TNC levels, most likely because postponed dormancy extended photosynthetic activity, allowing for more carbohydrate production.

COLORANTS

There is little published research on paint or colorants used to provide color to dormant turfgrass. In a study of colorants on dormant buffalograss performance, results showed that colorant treatments improved visual color ratings at all times compared to the control, increased canopy and soil temperatures, and enhanced spring green-up (Shearman et al., 2005). There were no phytoxicity effects from the use of the colorants, and it was noted that green-up began two weeks before the control plots, and was positively correlated with increased soil temperatures at the 50.8 mm soil depth (Shearman et al., 2005).

The only similar research for bermudagrass putting greens was found in industry literature, and supports the results of Shearman et al. (2005). On a TifEagle putting green, painted plots provided statistically equal visual ratings to overseeded plots, and provided longer ball-roll than overseeded plots (Liu et al., 2007). Furthermore, all painted treatments had slightly higher surface and soil temperatures, which were significant enough to enhance spring green-up compared to the overseeded and control plots. Differences in paint quality and longevity were found between paint brands, but none were affected by the use of TE, foliar fertilizer, or light to moderate foot traffic (Liu et al., 2007). The authors noted the need for further research examining the effects of painting on weed control, and heavy traffic on painted greens.

A recent study of paints used for athletic fields was initiated because field paints are formulated to not acutely injure turf, however repeated applications often result in chronic declines in turfgrass health (Reynolds et al., 2012). In that study, pigments used for athletic field paint were found to have the ability to reduce turfgrass growth through the absorption of photosynthetically active radiation (PAR) that would otherwise be used by the plant, as well as altering the spectral quality within PAR (Reynolds et al., 2012). This was found to be due to the role of pigments to create opacity on the plant surface to hide or cover the surface, and reflect a desired wavelength. This quality is provided by the base used to formulate the pigment, which is typically TiO_2 (titanium dioxide), C, or Fe_2O_3 (iron oxide). The study focused on the use of red, white and black paint and the authors noted the need for further research testing additional colors, products, rates and timing (Reynolds et al., 2012). This study took place on actively growing turfgrass in growth chambers, and did not address the use of colorants on semi-dormant nor dormant turf in the field.

OBJECTIVE

The null hypothesis for this study was that the traditional practice of overseeding a TifEagle bermudagrass green with *Poa trivialis* does not affect the bermudagrass quality. In addition, the fertilization (via N), and usage of the green surface (via golfer traffic) during the dormant season does not affect bermudagrass quality. Therefore, the objective of this research was to examine the combined effects of overseeding with *Poa trivialis*, N rate and traffic on the performance and quality of a hybrid bermudagrass TifEagle putting green.

MATERIALS AND METHODS

Research was conducted at the Auburn University Turfgrass Research Unit in Auburn, AL from October 2011 until June 2012, and from October 2012 until June 2013, on an 8 year old 'TifEagle' bermudagrass green. Soil type was a Marvyn loamy sand (fine-loamy, kaolinitic, thermic Typic Kanhapludult). The experiment design was a 4x2x2 factorial arrangement of N rate (0, 0.5, 1.0, and 2.0 g N m^{-2}) and overseed (yes or no), with those plots split in traffic (Yes or No). Main plots (N rate/overseed) measured 1.5 x 3 m, with the split (traffic) measuring 1.5 x 1.5 m. Overseeded plots were seeded with 'Sabre' *Poa trivialis* on November 9, 2011 and November 21, 2012 respectively, at a seeding rate of 49 g m^{-2} on a Pure Live Seed basis. Seed germinated by November 14, 2011 and November 28, 2012 respectively.

Nitrogen treatments were applied monthly beginning 16 Nov 2011 and again 2 Dec, 12 Jan, 9 Feb, 8 Mar, 10 Apr, and 2 May 2012. This was repeated in the second year beginning 3 Dec 2012, and again 7 Jan, 5 Feb, 13 Mar, 17 Apr, and 15 May 2013. Nitrogen source was urea (46-0-0) applied as a liquid to each plot with a CO_2-powered backpack sprayer calibrated at 28 ml m^{-2}, using 8004 flat fan TeeJet nozzles (TeeJet Technologies Southeast, P.O. Box 832 Tifton, GA 31794) and irrigation was applied immediately following application to limit N volatilization. Traffic simulation was performed using a modified walk-behind greens mower with two drums fitted with golf spikes, with a limited slip differential between drums to simulate golfer foot-traffic. Traffic was applied twice per week from January 1 to April 30 each year, with 15 passes made across each replication, to simulate heavy levels of traffic approximately equal to 40,000 rounds of golf per year.

At the conclusion of Year 1 the entire research area was vertical mowed in three directions and fertilized with N at 4.9 g m^{-2}. The area was maintained as a bermudagrass putting green throughout the summer (June-September), with mowing 5 of 7 days at 3.5 mm. Year 2 treatments were installed in the same plots as in Year 1, with the second year of work initiated with overseeding.

In both years of work the following data was collected: fall and spring total nonstructural carbohydrate (TNC) content; monthly shoot density; weekly vertical growth measurements; dry clipping weight at 1 and 3 WAT; leaf N content at 1 and 3 WAT; weekly qualitative color and quality ratings; and monthly stimpmeter measurements. Details for each procedure follow.

Prior to overseeding, two core samples per plot were taken for initial TNC analysis (Smith et al., 1964). Core samples (5.7 cm diam.) were taken to a depth of 5.5 cm, sealed in plastic bags and immediately stored in a cooler with ice on location. Processing of the cores occurred the same day as harvesting, and involved removing the turf canopy, and breaking up the remaining sample to remove all of the soil and thatch, leaving only roots, rhizomes and stolons, which were then placed in a paper bag and freeze dried. Dry soil was then removed from the samples by hand using a coarse sieve. Cleaned samples were next finely ground through a 1 mm Wiley mill screen. Samples (0.20 to 0.25 g) were boiled in 50 mL of 0.05 N H_2SO_4 for 1 h and placed in a shallow ice bath, after which 1.0 N NaOH was added to adjust the pH of the sample to 4.5. One mL of diluted amyloglucosidase (Aspergillus niger, Lot No. A 9913, Sigma-Aldrich Inc., St. Louis, MO) solution was added, and the samples then covered and incubated at

60^0C for 1 h. Samples were filtered and brought to volume in a 250-mL volumetric flask with 2 mL of 0.1 *N* NaOH and deionized H_20. Ten milliliters of Sheffer-Somogyi reagent (AOAC, 1995) were combined with a 10-mL aliquot of sample in a 25 x 200 mm capped test tube and boiled for 15 min. Tubes were then cooled in an ice bath, and 2 mL of potassium iodide-potassium oxalate solution was added to each sample. Next, 10 mL of 1.0 *N* H_2SO_4 and 1 mL of gelatinized starch solution were added to each tube before titration. Samples were titrated with 0.02 *N* sodium thiosulfate until the solution turned light blue. The concentration of TNC in samples was calculated as the amount of reducing sugar in the sample, multiplied by the dilution factor x 100, divided by the sample weight. Carbohydrate data was collected on 9 Nov 2011 and 5 Apr 2012 for Year 1, and on 22 Oct 2012, 29 Apr 2013, and 22 May 2013 for Year 2.

Shoot density was determined using a destructive sampling technique. In each plot, three (2.0 cm diam. x 7.6 cm deep) samples were taken. In the laboratory, each distinct shoot (a shoot was considered a node that produced leaf tissue) was hand-separated, counted and recorded. For overseeded plots, *Poa trivialis* shoots were separated from bermudagrass shoots and tallied separately. In Year 1, shoot density was obtained monthly from 9 November until 5 April. When traffic wear became visually noticeable in February, samples for the trafficked side of plots were taken separately. The same procedure was followed for Year 2, with sampling dates occurring monthly from 23 October until 5 May.

Vertical growth of the grass was measured weekly using a grass height prism gauge (Turf Tec International, Tallahassee, FL). The prism is a device that lays flat on the surface, with weight sufficient to settle into the turf canopy and show relative height of the grass against a scale printed on the side. The interpreter can then look down at a mirror and read the height of the grass. This was performed immediately following a mowing, and each day following until the next mowing to measure how much each plot grew. Measurements were taken for 5 inter-mowing periods in Year 1 and 3 periods in Year 2. This procedure was implemented in Year 1 because of the difficulty obtaining clean clipping samples due to sand and debris, a byproduct of the relatively low quality of the putting green leading into Year 1. The improved quality and health of the putting green leading into Year 2 provided clipping yields without sand and debris.

At 1 and 3 WAT dry clipping weights were taken from each plot. Clippings were collected for each plot using a standard walk-behind greens mower bucket, which was emptied for each plot into a paper bag, which was then placed in a plant dryer at 60C for 24 h to remove moisture from the plant tissue. The entire contents of each bag was then weighed and recorded. After weighing, a subsample was taken for each plot for leaf tissue N analysis. Tissue nitrogen was measured using a combustion analyzer (Plank, 1992)(LECO FP-328 protein/nitrogen analyzer, LECO Corp., St. Joseph, MI).

Qualitative color ratings were performed using a 1-9 visual rating scale, with 1= completely brown turf, and 9= lush, dark green turf. Qualitative quality ratings were performed using a 1-9 scale, with 1= bare soil exposed, and 9= very dense turf. Color and quality ratings were taken each week of the experiment in each year from October through April.

Green speed, a measure of golf ball roll, was measured monthly using a modified stimpmeter, as described by Gaussoin (1995). When traffic wear became noticeable in January of each year, both traffic and non-traffic halves of each main plot were measured separately. After mowing, a 19 cm long modified USGA stimpmeter was used to determine ball roll on each plot. This was done by releasing three golf balls down the stimpmeter held at a consistent height, and measuring the distance each ball rolled. To eliminate the element of slope in the green influencing the distance each ball rolled, the procedure was repeated in the opposite direction as the first three rolls. The distance each ball rolled in both directions was then averaged to determine green speed for each plot.

Background turfgrass management included mowing the green with a walking greens mower at heights of 3 to 4 mm, as needed throughout the week based on seasonal requirements (typically 5 of 7 days a week). Irrigation was applied as needed (typically 3-4 times a week), to provide 2.5 cm of water per week. Fungicides were utilized throughout the year on a preventative schedule, following recommended label instructions.

During the summer 2012, between years, the green was managed to decrease thatch, increase shoot density, and improve overall health of the bermudagrass. Vertical mowing was performed with a Graden vertical mower (Graden Turf Machinery, 29 Scammel Street, Campbellfield, Victoria, Australia) with 1-mm wide cutting blades set 2.6 cm apart, and set to a depth of 2.5 cm. Verticutting was performed in 3 directions each time, with the entire plot area vertical mowed in July and August. Core aerification was performed in addition to vertical mowing, with coring done in July and August, using 1.27 cm hollow tines with a 5 cm spacing (Ryan GA 30, Cushman, Inc., Lincoln, NE). After any cultivation, debris was removed from the green with snow shovels and blowers and sand topdressing was applied to fill in any holes or gaps, with irrigation immediately following. Background soil fertility (P, K and lime) was applied as needed and according to soil test. Nitrogen was applied weekly from June through August at a rate of 0.62 g m^{-2}. To aid in recovery and increase density of the turf, trinexapac-ethyl was applied one time in July and again in August at the recommended label rate of 657 ml ha^{-1}. All cultural maintenance treatments and fertilizing stopped at the end of August to prevent interference with the study, to begin in mid-October.

The method by which *Poa trivialis* was seeded altered from year to year. In the Year 1, the entire green was overseeded with *Poa trivialis*. After establishment, plots not requiring overseed were sprayed with foramsulfuron at a 583 ml/ha^{-1} rate, to remove *Poa trivialis*. In Year 2, *Poa trivialis* was only seeded into plots requiring that treatment. This was an effort to avoid differential herbicide application in the study. However, due to *Poa annua* germination in the non-overseeded plots, an application of foramsulfuron was again required for Year 2.

The SAS procedure PROC ANOVA was used to evaluate combined and separate responses to N rate, overseeding and traffic. Because Year of Study was significant, statistical analyses were run by Year. Tables 1 and 2 illustrate the significance of interactions, when analyzed over the sampling dates for each treatment variable.

RESULTS AND DISCUSSION

Statistical Analysis

In 2012, there were no significant 3-way interactions between overseeding, traffic and N rate across the measured variables (Table 1), and the same results were observed in 2013 (Table 2). Two-way interactions of Overseeding x N Rate and Overseeding x Traffic always affected clipping yield, largely because clipping yield was often a combination of bermudagrass and the overseed in those plots. Main effects of overseeding, N rate, and traffic were more often significant, with overseeding, N rate, and traffic all affecting clipping yield, bermudagrass shoot density, and growth of bermudagrass in both years. Least affected were clipping N content, golf ball roll (via stimpmeter) and shoot density of *Poa trivialis*. These variables had some significant responses to N (ball roll in 2012; clipping N content in 2013), traffic (*Poa trivialis* shoots and ball roll in 2012 only) or overseeding (*Poa trivialis* shoots and clipping N in 2013 only).

Effects of Overseeding on Shoot Density of Bermudagrass

Bermudagrass shoot density has been shown to be higher without competition from overseeding (Horgan and Yelverton, 2001). In this study, shoot density of the bermudagrass was affected by the presence of the *Poa trivialis* overseed. Winter growth of the overseeding created competition with the bermudagrass, with subsequent declines in bermudagrass shoot density as compared to that bermudagrass that had not been overseeded. In 2012, shoot density was not measured until March, at which time bermudagrass shoot density was already significantly decreased by the presence of the overseed (Table 3). In 2013, bermudagrass shoot density was monitored for a longer period. A negative effect was first observed in February, with a significant decrease in bermudagrass shoots in overseeded plots (Figure 1; Table 4). The effect of *P. trivialis* competition on bermudagrass shoot density remained significant beyond spring green-up, which occurred by early April in both years. A significant difference in shoot densities in 2013 due to overseeding was still present in mid-June. Bermudagrass in overseeded plots did not fully recover (although this was a non-significant shoot density, as compared to non-overseeded plots) until mid-July in 2012, and had not yet fully recovered as of the last sampling date of 2013. Non-overseed plots had significantly more bermudagrass shoots in May of both years as compared to overseeded plots (Tables 3 and 4).

One of the benefits of using *P. trivialis* for overseeding is typically attributed to its lack of heat tolerance, allowing for an earlier natural transition compared to perennial ryegrass (Toler et al., 2003). This study did not compare overseed species (perennial ryegrass or *P. trivialis*), but in both years *P. trivialis* persisted beyond June. Other research has found similar persistence with *P. trivialis* (Hollingsworth et al. 2005). This may suggest that highly maintained turf like golf greens, with their frequent water, fertilizer, and fungicide applications, assist in prolonging the presence of *P. trivialis* in the southeast. More research is needed to understand the long-term effects of a late transition occurring for several consecutive years on the quality of the ultradwarf hybrid bermudagrasses. Previous research found long-term effects of repeated overseeding delayed transition, as it reduced the amount of energy the bermudagrass could create and store for the following year (Mazur and Wagner, 1987), but that research was not performed on an ultradwarf bermudagrass putting green. Dormant bermudagrass survives on carbohydrates and other photosynthates accumulated during the previous growing season, and extended competition from overseed can extend dormancy of bermudagrass into the spring (Horgan and Yelverton, 2001). If stored carbohydrates are depleted before the plants green up, this may result in winter kill (Anderson et al. 2003; Richardson, 2002). In the two years of this study, no winter kill was observed on any research plots.

Another factor involved with a natural transition was N application early in the spring. Horgan and Yelverton (2001) found that early N application significantly increased the rate of ryegrass disappearance, and allowed bermudagrass shoot density to increase. They proposed that N uptake by the bermudagrass resulted in greater competition with the perennial ryegrass as the summer progressed. The same conclusion was offered by Hollingsworth et al. (2005), with *P. trivialis* on a TifEagle putting green.

In our work, differences in the greens' quality were observed, with shoot density that was approximately 50% greater in Year 2. However, despite this difference in overall health, the bermudagrass did not fully overcome the effects of the overseed competition until mid-summer in both years. In a golf course setting where quality of the greens is always scrutinized, this may be a significant factor for deciding to overseed or not for winter play. This study was performed on a TifEagle green, and other ultradwarf cultivars may have quicker growth rate to help overcome overseed competition.

Effects of Traffic on Shoot Density of Bermudagrass

As an abiotic stress, foot traffic can affect turfgrass shoot density when applied continuously (Carrow and Petrovic, 1992). Signs of traffic wear are generally evident by abrasion, tearing, or stripping of leaf tissue, which opens up the canopy and reveals bermudagrass stolons (Trenholm et al., 2000). In the winter when the bermudagrass is dormant, new growth does not occur, or is too slow to initiate and replace lost leaf tissue. Dormant ultradwarf bermudagrass has been shown to be highly tolerant to light to moderate foot traffic, but the effects of heavy traffic have not been studied (Liu et al., 2007).

Traffic simulation began for both years in early January, and effects were observed in the turfgrass as the simulation progressed through the winter. Collection of bermudagrass shoot density samples did not begin in Year 1 until March, but visual ratings indicated the effects of wear (Table 5). Visual ratings of turfgrass wear have been found to be highly correlated to sampling analysis (Shearman and Beard, 1975). In Year 2, cumulative wear of traffic became evident in mid-February, when shoot density in trafficked plots was decreased (Table 6). The effect of traffic remained throughout March and April, as the bermudagrass was not growing at a rate sufficient to overcome the effects of the wear. However, as temperatures increased in April and the bermudagrass began to grow, differences in shoot density as affected by traffic were less obvious, with no significant difference in July 2012, or May, 2013 (Tables 5 and 6; Figure 2). June 2013 is of interest, as the traffic plots surpassed non-traffic plots in shoot density. Although not significant, this may be similar to results observed by Carrow et al. (1980), where compaction related to traffic initiated new tiller growth as a function of higher ethylene levels in the compacted soil. It may also be a function of the golf spikes on the traffic simulator cutting the bermudagrass stolons and creating a new growth point.

The difference in recovery rates between years is likely related to the improved overall health of the green from 2012 to 2013. Faster recovery was expected, as several previous studies have noted that turfgrass recovery is species specific, dependent on growth rate, degree of severity of the injury, and most importantly, the time of year the injury occurs (Trenholm et al., 2000; Lulli et al., 2012). In this study, effects of traffic were outgrown more quickly in Year 2, several months faster than in Year 1. This may suggest that with a healthy TifEagle green, overseeding is more detrimental to the health of a bermudagrass green than is traffic.

Effect of Traffic on Shoot Density of Poa trivialis

In this study, there was only one sampling date in 2012 in which traffic significantly affected *P. trivialis* shoot density (Table 7; Figure 4). In Year 2 the population of *P. trivialis* population was never affected by traffic, and only by sampling date (data not shown). The difference between the two years may be related to the improved overall health of the bermudagrass from Year 1 to Year 2, where the more dense bermudagrass in Year 2 may have provided more wear protection to the *P. trivialis*. This study did not evaluate a pure stand of *P. trivialis* and its ability to withstand traffic wear alone.

Nitrogen Rate

Use of N though the winter months is needed for the growth and healthy appearance of the overseeded grass. Higher N rates were expected to impart better wear tolerance for the overseed by increasing the rate of growth of the *P. trivialis*, thus making it better able to outgrow traffic injury (Trenholm, 2000; Lulli 2012). Nitrogen rates of 0, 0.5, 1.0, 2.0 g m^{-2} were utilized, with significant differences observed in clipping weight and vertical growth during both years. Bermudagrass shoot density was significantly affected by N Rate in 2012, and less so in 2013 (Figure 4). Total N content of clippings was significantly increased with increasing N in

2013, but not in 2012 (Tables 1 and 2). The highest N Rate of 2.0 g N m^{-2} was needed for maximum turfgrass color in both non-overseeded and overseeded plots (Figures 5-12).

When the quality of non-overseeded plots was evaluated, the quality of dormant, non-overseeded bermudagrass was not affected before March in each year. Differences due to N Rate were not observed until late March in Year 1 (Figure 14) and were not easily distinguishable in Year 2 at any time (Figure 15). In 2012, both trafficked and non-trafficked plots were affected by N Rate, with the highest N Rate producing the best color from March through May (Figures 13 and 14). In 2013, there was no effect of N rate on bermudagrass color or quality, regardless of traffic (Figures 15 and 16). This is likely a temperature effect. In 2012 February and March average high temperatures for those months were 17.5 and 24.3C, respectively, while in 2013 average high temperatures for those months were 15 and 16.7C respectively. Although average minimum low temperatures were similar in both years (December-April), in 2012 there was greater fluctuation between high and low temperatures, resulting in bermudagrass that was less likely to go completely dormant and would thus be utilizing and responding to applied N. For example, in March of 2012 the highest temperature on one day was 30C, while the highest in March of 2013 was 26C.

For the *Poa trivialis* overseed, highest quality was also observed with the highest N Rate. Differences were more apparent in 2012 than 2013, with a slight difference in Year 1 due to traffic (Figures 17 and 18), likely a result of the poorer bermudagrass in 2012, which allowed more *Poa trivialis* to grow and utilize applied N. In Year 2, no differences were observed in quality of the overseed, regardless of traffic, until the last date when the highest N Rate did improve quality as compared to the other N rates (Figures 19 and 20).

Clipping yield from overseeded plots increased with increasing N Rate in all 8 sampling dates in 2012, with significant differences between the control and plots receiving N on December 13, and then between the highest N rate and all other rates from January 12 until April 1. By February 17, the two highest N rates produced more clippings, and that trend remained for the duration of Year 1 (Table 8; Figure 21). This effect was repeated in Year 2 (Table 9; Figure 22), beginning with the December 10 sampling date and continuing until April 5. Plots receiving 2.0 g N m^{-2} produced significantly more clippings than harvested from other plots. Since this data represents clipping harvests over a range of samplings, it should be noted that the dry weights are from an average of *Poa trivialis* and bermudagrass, with fluctuations in species composition due to time of year.

Clippings were not taken from non-overseeded plots from January until April in 2012 because mowing was negatively affecting the quality of those plots due to the low quality of the green. In 2013, clippings were removed from all plots on all dates. To aid in quantifying growth without mowing, vertical height measurements were taken with a growth prism in 2012. Results of those measurements showed significant increases in growth due to N rate on 2 of the 5 sampling dates (Table 10). In all cases growth of the grass increased as N rate increased (2012). In 2013, N Rate effects were not observed until April, when growth again increased linearly with increasing N rate (Table 11).

The main effects of N rate, traffic and overseeding all affected bermudagrass shoot density, in both years, but there were no significant interactions (Tables 1 and 2). In 2012 shoot density of bermudagrass increased with increasing N, up to the highest rate of 2.0 g N m^{-2}. The exception was in March, when density was maximized at 1.0 g N m^{-2}. The reduced N rate response was also observed in 2013, when shoot density was not significantly affected by N until

March, when increasing N increased shoot density (March and May 2013)(Tables 12 and 13). These tables also illustrate the difference in bermudagrass quality, as related to shoot density, between Year 1 and 2, with the highest shoot count of Year 1 equal to the lowest count of Year 2. By the summer of 2013, shoot densities were approximately 50% greater than in the summer of 2012. When the main effect of N is evaluated, increasing rates of N did not always increase shoot density. As the bermudagrass grew and utilized applied N in the spring, shoot density did increase, but there were no effects of increasing N in December to February (Tables 12 and 13).

Dry clipping subsamples were analyzed for tissue N content at every clipping collection date. In 2012, no treatment variable affected tissue N (Table 1), while in 2013 both N, overseeding, and their interaction affected tissue N (Table 2). Tissue N content of the overseed was consistently increased by N rate at each sampling date, excluding the first. The same trend occurred with the bermudagrass, beginning in February. Differences between the overseeded and non-overseeded plots were not consistent either by N rate or sampling date (Table 14). This data is contrary to expectations, because the dormant or semi-dormant bermudagrass contained similar N concentrations as the actively growing overseed. This may be due to the repeated monthly N applications applied to all plots regardless of overseed treatment.

Golf Ball Rolling Distance (Stimpmeter)

Ball roll distance, measured with a modified USGA stimpmeter, was not consistent throughout the course of the study. In 2012 only traffic and N rate affected ball roll, while in 2013 no treatment affected ball roll (Tables 1 and 2). In Year 1, ball roll distance was not consistent as N rate increased (Table 15). Traffic affected ball roll in 2012 on one date, but was not a consistent factor (Table 16). In 2013 traffic increased ball roll in only 1 of 4 dates (Table

17). There were no differences in ball roll between overseed and non-overseeded plots, or N rate in either year, which was surprising because it was expected that the overseed growth, influenced by N rate, would create more friction and slow the ball.

Ball roll is a concern for turf managers in this region, as one of the concerns with ultradwarf playability in the winter is that the green speed increases through the winter as the dormant canopy is compacted by equipment and foot traffic, to the point of being beyond control by the average golfer. As a result, some managers appreciate overseeding because it allows them more control over their green speed without losing control of ball roll. These concerns were not validated in this study, as ball roll was unaffected by the presence or absence of the overseed.

Quality

Relative visual quality scores showed the impact of traffic on the greens' surface for both overseed and non-overseed plots. In 2013, the non-trafficked plots maintained their relatively high quality rating throughout the winter (Figures 23 and 24). These results were expected, because without traffic wear to tear leaf tissue and open the canopy, the leaf tissue remained in place regardless of being dormant. As such, the quality of the surface at spring green-up was directly related to the quality of the surface entering the dormancy period. Overseed did not improve quality of the green at any time during the winter of 2013. This is an indication of the high quality bermudagrass surface during dormancy, as the quality scores were sufficiently high to make a notice in improvement difficult to achieve when using averages. Considering the seeding rate and N rates used in this study, it may be possible to increase quality on similarly quality bermudagrass using greater seed and fertilizer inputs. However, the finding of this research would suggest such actions would negatively affect the bermudagrass in its subsequent spring transition.

Overseed and non-overseed quality scores in 2012 differed considerably when compared to 2013 data, due to the lower quality of the green entering dormancy (Tables 25 and 26). Starting from a lower quality level, quality was maintained in January and February, but deteriorated slightly in March before rebounding with the warmer weather in late March. Due to previous research on the TifEagle green, little to no N had been applied to the green prior to this study beginning. The increase in quality in March is likely a combination of warmer weather and N finally being provided to the turf. This is evidenced in the general slope of both trafficked and non-trafficked lines from late-March onward. The trafficked line is particularly interesting, as the bermudagrass maintained its’ quality after months of accumulated wear better than it did in 2013. However, the lowest ratings in 2013 were still equal or better than the highest rating in 2012.

The overseeded plots also maintained quality throughout 2012, but the transition caused slight drop in quality due to the dying overseed. The surface area maintained by the overseed during the winter was not immediately covered up by the growing bermudagrass, leaving slight unevenness of the turf canopy (Figure 25). For golf course greens, this unevenness is not ideal for ball roll characteristics or aesthetics, and is thus viewed negatively. This is one of the main problems cited with spring transition of overseed on golf courses as it relates directly to the playing conditions of the greens (Horgan and Yelverton, 2001; Mazur and Rice, 1999). In contrast, the non-overseed plots maintained an upward trend at this same time period, as the quality was continuing to improve (Figure 26).

Trafficked plots in 2013 were similar in quality throughout the course of the winter, regardless of having overseed or not (Figures 23 and 24). Overseed did not provide protection to the bermudagrass or a better quality surface under high traffic stress in either year of this study (Figures 23-26). In both years bermudagrass shoot density was negatively affected via competition for space by the overseed (Table 3 and 4). This was contrary to the suggestion of Thoms et al. (2010). Furthermore, the bermudagrass was able to overcome the traffic damage inflicted in this study faster than it could overcome overseed competition. Although surprising, the overseed did not provide a better quality surface than the semi-dormant bermudagrass. Previous research on overseeded athlete fields ranked *P. trivialis* poorly for wear tolerance (Shearman and Beard, 1975), and bermudagrass in general is known for high wear tolerance and recuperative ability (Deaton and Williams, 2010).

The density of the bermudagrass from year to year was an important factor in the results observed each year. They are also directly related to conclusions of Deaton and Williams (2010), despite their study occurring on bermudagrasses for athletic field use. They found that more dense bermudagrass cultivars did not benefit from overseed with simulated traffic. As an ultradwarf hybrid bermudagrass, TifEagle is one of the most inherently dense cultivars of the *Cynodon* genus, and known for its excellent dormant playing surface (Liu et al., 2007). As such, it was not surprising that the healthier and denser turf of Year 2 did not benefit from overseed. However, it was interesting that even with the lower shoot density in Year 1, overseed could not improve the quality of the playing surface compared to the bermudagrass alone.

Color

Relative visual color ratings captured the state of dormancy in the bermudagrass, growth periods, and color differences between overseeded and non-overseeded plots (Figures 27-30). Non-overseeded plots varied more widely in visual color rating ranging from a score of 1 when completely dormant and brown, to a high of 6 when actively growing and producing chlorophyll. High N rates applied during the winter months provided more color to the turf during warmer periods, with color increasing successively with increasing N rate to a maximum rating of 6 (Figures 6-9). Color ratings, averaged over the winter months from December to April, were between 2 and 3 each year, well below the minimum ‘acceptable’ rating of 5. For a golf course setting, these low color ratings suggest the need for supplementing color to the turf for an appealing green appearance.

Overseeded plots routinely received higher visual color ratings due to the inherent ability of the cool-season grass to grow in cool weather and maintain a green color. As a result, color loss during cold periods was mitigated compared to the non-overseed plots, with a minimum rating of 2 in 2012 (Figures 10-13). This low rating was due to poor overseed growth in the unfertilized plots. Color ratings did increase during warmer periods of the winter, and increasing N was important throughout the winter to provide more green color. Plots that received 0 N during the study were consistently rated significantly lower than the higher N rate plots beginning in January, and continuing through April. Average color ratings for overseeded plots were from 4 to 5 each year. These scores still fall below or barely meet the minimum ‘acceptable’ rating of 5, but this is likely a different result than would occur on a golf course due to the intensive fertilization during the overseed establishment period that would occur in a golf setting, but was not part of this experimental procedure.

Trafficked plots uniformly received lower color scores than their non-trafficked counterparts for both overseeded and non-overseeded treatments from February through April (Figures 27-30). Effects of traffic became evident in February, due to the shearing off of leaf tissue, exposing the underlying tan bermudagrass or white stolons and effectively diluted the greenness of the plot, resulting in a lower color rating. The lower rating for trafficked plots continued for the non-overseed plots until March in both years, at which time warmer weather prompted new growth from the bermudagrass, replacing the leaf tissue lost to traffic wear. Color ratings were equal in regard to traffic by early May in 2012, but were not equal in color by the mid-April in 2013 (Figures 27-30).

Summary

When comparing overseeded to non-overseeded plots in May each year, the highest N rate for each respectively provided nearly identical color and quality ratings (Figures 5 and 7). However, there were significant differences in bermudagrass shoot density at this time each year. Although the overseed plots with high N received slightly higher color and quality ratings, they did so at the expense of the underlying bermudagrass, by effectively crowding out the bermudagrass and taking up more space. The result of the overseed competition was delayed growth of the bermudagrass. In a golf course setting, this delay of the bermudagrass dominance would add pressure to the timing and quality of the transition period to provide uninterrupted surface quality. Considering all factors observed in this study, it is not recommended to overseed ultradwarf bermudagrass putting greens to improve winter playing conditions or appearance in this region, unless the shoot density is low to medium compared to a healthy and well maintained green of the same cultivar. This recommendation may also depend on the use of herbicidal transitions.

Conclusions:

1. In this region, bermudagrass does not remain fully dormant during the winter, but rather fluctuates in a semi-dormant state, and responds to warmer periods with new growth. As such, turf managers need to understand the impact of their winter cultural and fertility programs on the ultradwarf putting greens.
2. Bermudagrass was able to produce new shoots during the course of the winter when receiving the highest N rate (2.0 g N). This is another sign of the semi-dormant state of the ultradwarfs, which may aid in maintaining appropriate green speed throughout the winter months.
3. Color and quality of bermudagrass was significantly better in early spring with the highest N rate, suggesting the benefit of early season N application to bermudagrass.
4. Overseeding did not provide better traffic tolerance than bermudagrass alone.
5. Overseeding did slightly improve turf quality at the end of the winter, but only with the highest N rate, and in the process significantly reduced bermudagrass shoot density.
6. Due to reduced shoot density of bermudagrass, competition from overseeding significantly impacted the quality of the green surface during spring transition. Consideration should be given to the transition timing if overseeding will be utilized, to not interfere with playing surface performance during periods of high course play.
7. Considering all factors observed in this study, it is not recommended to overseed ultradwarf bermudagrass putting greens to improve winter playing conditions or appearance in this region.

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Table 1. Table of interactions of the various measured treatment variables from Analysis of Variance, 2012.

	Clipping Weight	Bermuda Shoot Density	*Poa trivialis* Shoot Density	Bermuda Growth	*Poa trivialis* Growth	Ball Roll	Total N in Clippings
Treatment Variable	P>F						
Overseed x Date	0.0001	0.0001	NS	0.0001	NS	NS	NS
Traffic x Date	0.0001	0.0001	0.0077	0.0001	0.0002	0.0001	NS
N Rate x Date	0.0001	0.0011	NS	0.0001	0.0235	0.0001	NS
N Rate x Traffic	NS	NS	NS	NS	NS	NS	NS
Overseed x N Rate x Date	0.0001	NS	NS	0.0294	NS	NS	NS
Overseed x Traffic x Date	0.0001	NS	NS	NS	NS	NS	NS
N Rate x Traffic x Date	NS	NS	NS	NS	NS	NS	NS
N Rate x Traffic x Overseed	NS	NS	NS	NS	NS	NS	NS

Table 2. Table of interactions of the various measured treatment variables from Analysis of Variance, 2013.

	Clipping Weight	Bermuda Shoot Density	*Poa trivialis* Shoot Density	Bermuda Growth	*Poa trivialis* Growth	Ball Roll	Total N in Clippings
Treatment Variable	———	———	———	P>F	———	———	———
Overseed x Date	0.0001	0.0093	0.0001	0.0001	NS	NS	0.0001
Traffic x Date	0.0001	0.0027	NS	0.0001	NS	NS	NS
N Rate x Date	0.0001	0.0783	NS	0.0001	NS	NS	0.0001
N Rate x Traffic	NS	NS	NS	NS	NS	NS	NS
Overseed x N Rate x Date	0.0001	NS	NS	0.0645	NS	NS	0.0001
Overseed x Traffic x Date	0.0356	NS	NS	NS	NS	NS	NS
N Rate x Traffic x Date	NS	NS	NS	NS	NS	NS	NS
N Rate x Traffic x Overseed	NS	NS	NS	NS	NS	NS	NS

Table 3. Effect of a *Poa trivialis* overseed on the bermudagrass shoot density of TifEagle hybrid bermudagrass as affected by overseeding and sampling date, 2012, Auburn, AL.

Overseed ‡	Date		
	March 22	May 9	July 23
	shoots cm^{-2}		
Yes	7.1 b†	8.9 b	12.8 a
No	9.7 a	11.2 a	12.1 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at $P \leq 0.05$.

‡ Overseed applied as 'Sabre' *Poa trivialis* at 49 g m^{-2} on November 9, 2011.

Table 4. Effect of a *Poa trivialis* overseed on the bermudagrass shoot density of TifEagle hybrid bermudagrass as affected by overseeding and sampling date, 2013, Auburn, AL.

Overseed ‡	Date					
	December 3	January 18	February 14	March 22	May 1	June 17
	shoots cm^{-2}					
Yes	16.2 a†	13.0 a	12.9 b	15.0 b	16.6 b	18.0 b
No	15.4 a	13.1 a	14.2 a	15.8 a	17.8 a	20.5 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at P≤0.05.

‡ Overseed applied as ‘Sabre’ *Poa trivialis* at 49 g m^{-2} on November 21, 2012.

Table 5. Effect of traffic on bermudagrass shoot density of TifEagle hybrid bermudagrass, by sampling date, 2012, Auburn, AL.

Traffic ‡	Date		
	March 22	May 9	July 23
		shoots cm^{-2}	
Yes	7.6 b†	9.0 b	12.3 a
No	9.2 a	11.0 a	12.7 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at P≤0.05.

‡ Traffic applied with modified walk-behind greens mower 15 passes per plot applied twice a week from January through April.

Table 6. Effect of traffic on bermudagrass shoot density of TifEagle hybrid bermudagrass, by sampling date, 2013, Auburn, AL.

Traffic ‡	Date					
	December 3	January 8	February 14	March 22	May 1	June 17
	shoots cm^{-2}					
Yes	15.8 a†	13.0 a	12.9 b	14.4 b	17.0 a	19.8 a
No	15.8 a	13.0 a	14.2 a	16.3 a	17.3 a	18.6 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡ Traffic applied with modified walk-behind greens mower 15 passes per plot applied twice a week from January through April.

Table 7. Effect of traffic on shoot density of *P. trivialis* on a TifEagle hybrid bermudagrass, by sampling date, 2012, Auburn, AL.

Traffic ‡	Date			
	February 8	February 22	March 22	May 9
	Shoots cm^{-2}			
Yes	10.0 a†	13.6 a	11.1 b	8.2 a
No	11.5 a	14.0 a	13.6 a	9.6 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡Traffic applied with modified walk-behind greens mower 15 passes per plot applied twice a week from January through April.

Table 8. Effect of N rate on clipping weight of *Poa trivialis* and TifEagle hybrid bermudagrass by sampling date 2012, Auburn, AL.

N Rate ($g\ N\ m^{-2}$) ‡	Date							
	December 13	January 12	January 19	February 2	February 17	March 1	March 15	April 1
	clipping yield $g\ m^{-2}$							
0.0	1.2 c†	0.9 c	0.4 b	2.3 c	0.3 d	0.9 d	1.3 c	5.7 c
0.5	1.4 bc	1.5 b	0.5 b	3.7 b	0.4 c	1.3 c	1.3 c	6.6 c
1.0	1.6 ab	1.8 b	0.5 b	4.4 b	0.6 b	1.7 b	1.8 b	7.9 b
2.0	1.7 a	2.6 a	0.9 a	7.3 a	1.3 a	3.5 a	3.5 a	10.9 a

† Overseed applied as 'Sabre' *Poa trivialis* at 49 $g\ m^{-2}$ on November 9, 2011.

‡N source was (46-0-0) urea.

Table 9. Effect of N rate on clipping weight of a combined harvest of *Poa trivialis* and TifEagle hybrid bermudagrass, by sampling date 2013, Auburn, AL.

N Rate (g N m^{-2}) ‡	Date							
	December 10	December 19	January 18	January 24	February 14	March 1	March 23	April 5
	clipping yield (g m^{-2})							
0.0	1.9 b†	2.6 c	3.2 d	2.5 c	2.9 c	1.7 c	1.4 c	1.2 c
0.5	2.1 b	2.6 c	3.9 c	2.7 c	3.5 b	2.1 b	1.6 bc	1.3 c
1.0	2.5 a	3.0 b	4.4 b	3.1 b	3.7 b	2.3 b	1.7 b	1.5 b
2.0	2.5 a	3.4 a	5.4 a	3.8 a	4.7 a	3.7 a	2.2 a	2.1 a

† Overseed applied as ‘Sabre’ *Poa trivialis* at 49 g m^{-2} on November 21, 2012.

‡N source was (46-0-0) urea

Table 10. Effect of N rate on vertical growth of *Poa trivialis* and bermudagrass, by sampling date, 2012, Auburn, AL.

N Rate (g N m^{-2}) ‡	Date				
	February 21	March 6	March 12	March 19	March 26
	vertical growth (mm)				
0.0	0.9 b†	0.7 b	2.8 b	1.8 b	2.0 b
0.5	1.3 ab	1.3 a	3.3 ab	2.5 ab	2.6 b
1.0	1.6 ab	1.2 a	3.4 ab	2.6 ab	2.6 b
2.0	2.8 a	1.8 a	5.0 a	3.9 a	7.4 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡N source was (46-0-0) urea

§ Vertical growth measured with grass height prism gauge (Turf Tec International, Tallahassee, FL), with the height shown in the Table representing grass height after 24-hr of growth after mowing.

Table 11. Effect of N rate on vertical growth of *Poa trivialis,* by sampling date, 2013, Auburn, AL.

N Rate (g N m^{-2}) [‡]	Date		
	March 8	April 5	April 22
	vertical growth (mm)		
0.0	2.0 a[†]	3.1 d	2.8 c
0.5	2.0 a	3.3 c	3.1 b
1.0	2.0 a	3.5 b	3.2 b
2.0	2.0 a	3.7 a	3.7 a

[†] Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

[‡] N source was (46-0-0) urea

§ Vertical growth measured with grass height prism gauge (Turf Tec International, Tallahassee, FL).

Table 12. Effect of N rate on bermudagrass shoot density of TifEagle hybrid bermudagrass by sample date, 2012, Auburn, AL.

N Rate ($g\ N\ m^{-2}$) ‡	Date		
	March 22	May 9	July 23
	shoots cm^{-2}		
0.0	7.7 c†	8.6 b	12.0 b
0.5	8.6 bc	9.7 a	12.1 b
1.0	9.2 ab	10.5 a	12.1 b
2.0	8.1 ab	11.3 a	13.6 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡N source was (46-0-0) urea.

Table 13. Effect of N rate on bermudagrass shoot density of TifEagle hybrid bermudagrass by sample date, 2013, Auburn, AL

N Rate ($g\ N\ m^{-2}$) ‡	Date					
	December 3	January 8	February 14	March 22	May1	June 17
	shoots cm^{-2}					
0.0	16.0 a†	13.3 a	13.3 ab	14.5 a	16.0 c	17.8 a
0.5	16.1 a	13.2 a	14.3 a	15.0 a	17.0 bc	18.0 a
1.0	15.4 ab	12.8 a	12.8 b	15.5 a	17.8 ab	17.8 a
2.0	15.8 a	12.8 a	13.7 ab	16.5 a	18.1 a	18.2 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡ N source was (46-0-0) urea.

Table 14. Effect of the interaction of Overseed x N Rate on Tissue N Content, by sampling date, 2013, Auburn, AL.

N Rate (g N m^{-2})‡	Date											
	December 10		January 18		February 14		March 1		March 22		April 5	
	% N content											
	Overseed											
	Y	N	Y	N	Y	N	Y	N	Y	N	Y	N
0	3.2 a†	3.0 b	3.6 ab	3.7 a	3.6 a	3.6 a	4.3 a	4.3 a	3.8 b	4.0 a	4.0 ab	4.1 a
0.5	3.0 b	3.3 a	3.8 a	3.6 b	3.6 a	3.6 a	4.4 a	4.4 a	3.9 a	4.0 a	4.2 a	4.2 a
1.0	3.1 a	3.3 a	4.6 a	4.5 ab	3.7 a	3.8 a	4.7 a	4.4 b	4.0 a	4.1 a	4.4 a	4.3 ab
2.0	3.3 a	2.9 b	4.8 a	3.9 b	4.1 a	3.9 ab	5.1 a	4.8 b	4.3 b	4.6 a	4.7 a	4.5 b

† Within each sampling date by N rate (across rows) means followed by the same letter are not significantly different from each other via means separation at α=0.05.

§ Overseed applied as 'Sabre' *Poa trivialis* at 49 g m^{-2}.

Table 15. Effect of N rate on ball roll distance, by sampling date, 2012, Auburn, AL.

N Rate (g N m^{-2}) ‡	Date		
	April 12	April 19	May 1
		distance (m)§	
0	3.6 a†	1.9 d	3.2 a
0.5	3.6 ab	2.5 c	3.1 ab
1.0	3.4 ab	2.9 b	3.1 ab
2.0	3.3 b	3.2 a	3.0 ab

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡ N source was (46-0-0) urea.

§ Ball roll distance based on 19 cm modified USGA Stimpmeter.

Table 16. Effect of traffic on ball roll distance, by sampling date, 2012, Auburn, AL.

Traffic ‡	Date		
	April 12	April 19	May 1
		distance (m)	
Yes	2.6 a†	1.7 b	2.2 a
No	2.3 b	2.0 a	2.2 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡ Ball roll distance based on 19 cm modified USGA Stimpmeter.

Table 17. Effect of traffic on ball roll distance, by sampling date, 2013, Auburn, AL.

Traffic ‡	Date			
	March 8	April 5	April 22	May 2
	distance (m)			
Yes	3.3 a†	3.4 a	2.7 a	2.6 a
No	3.3 a	2.6 b	2.8 a	2.6 a

† Within each sampling date means followed by the same letter are not significantly different from each other via means separation at α=0.05.

‡ Ball roll distance based on 19 cm modified USGA Stimpmeter.

Figure 1. The effects of a *Poa trivialis* overseed on the shoot density of TifEagle hybrid bermudagrass, by sampling date, 2013

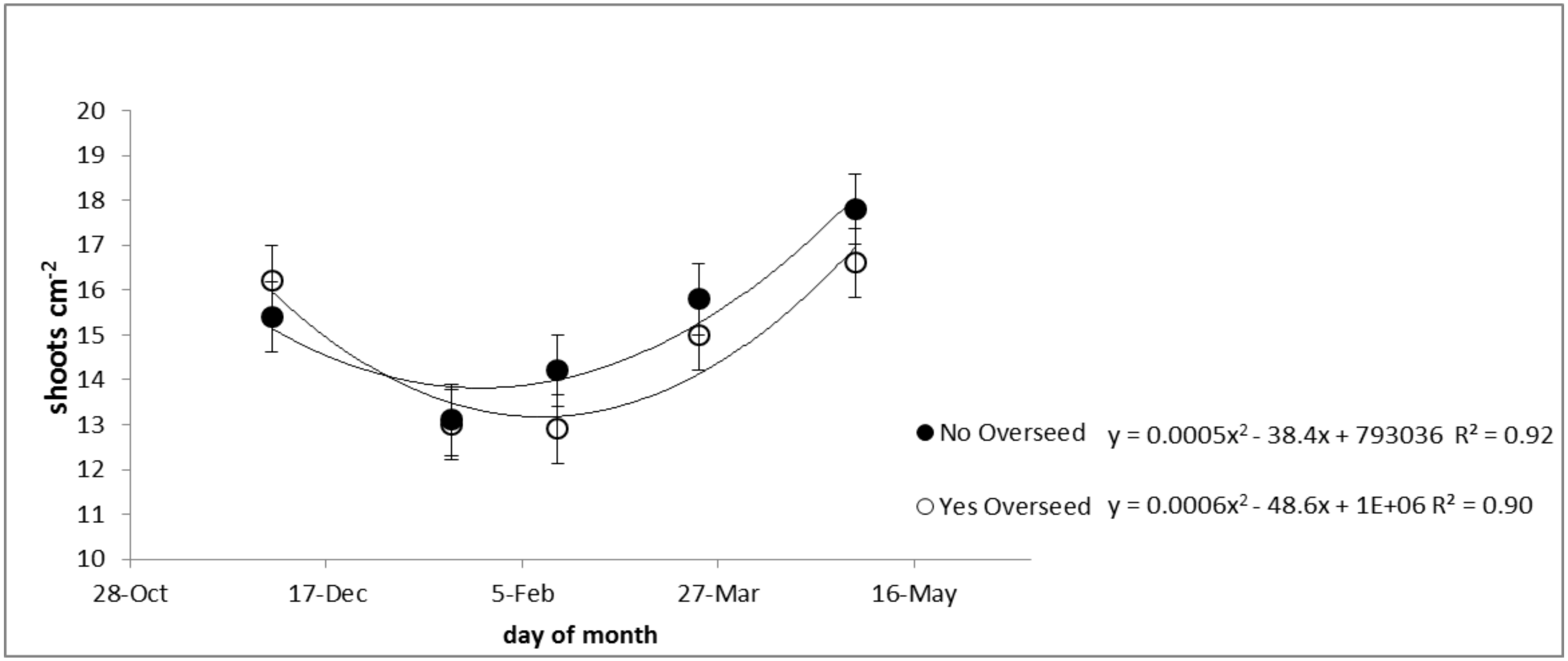

Figure 2. Effect of traffic simulation (performed two times per week from January through April) on TifEagle hybrid bermudagrass shoot density, by sampling date, 2013

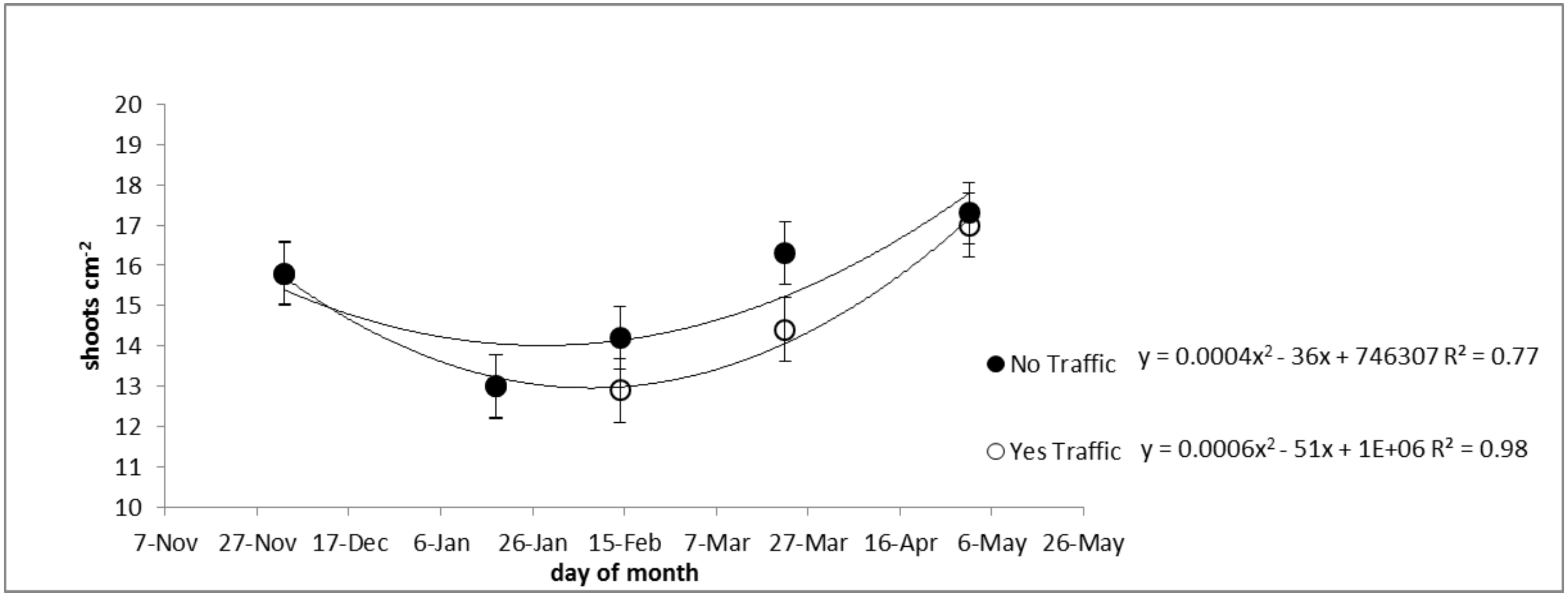

Figure 3. Effect of traffic simulation (performed two times per week from January through April) on *Poa trivialis* shoot density by sampling date, 2012

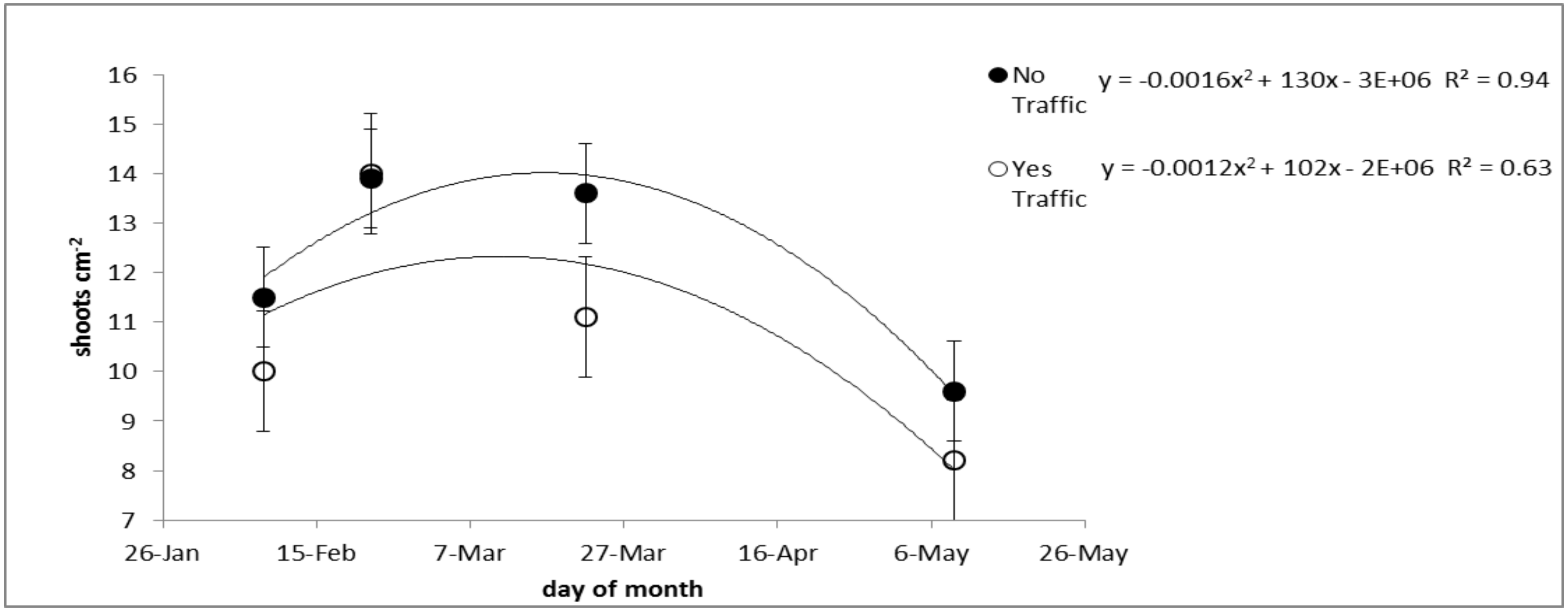

Figure 4. Effect of N rate (applied monthly) on TifEagle hybrid bermudagrass shoot density by sampling date, 2013

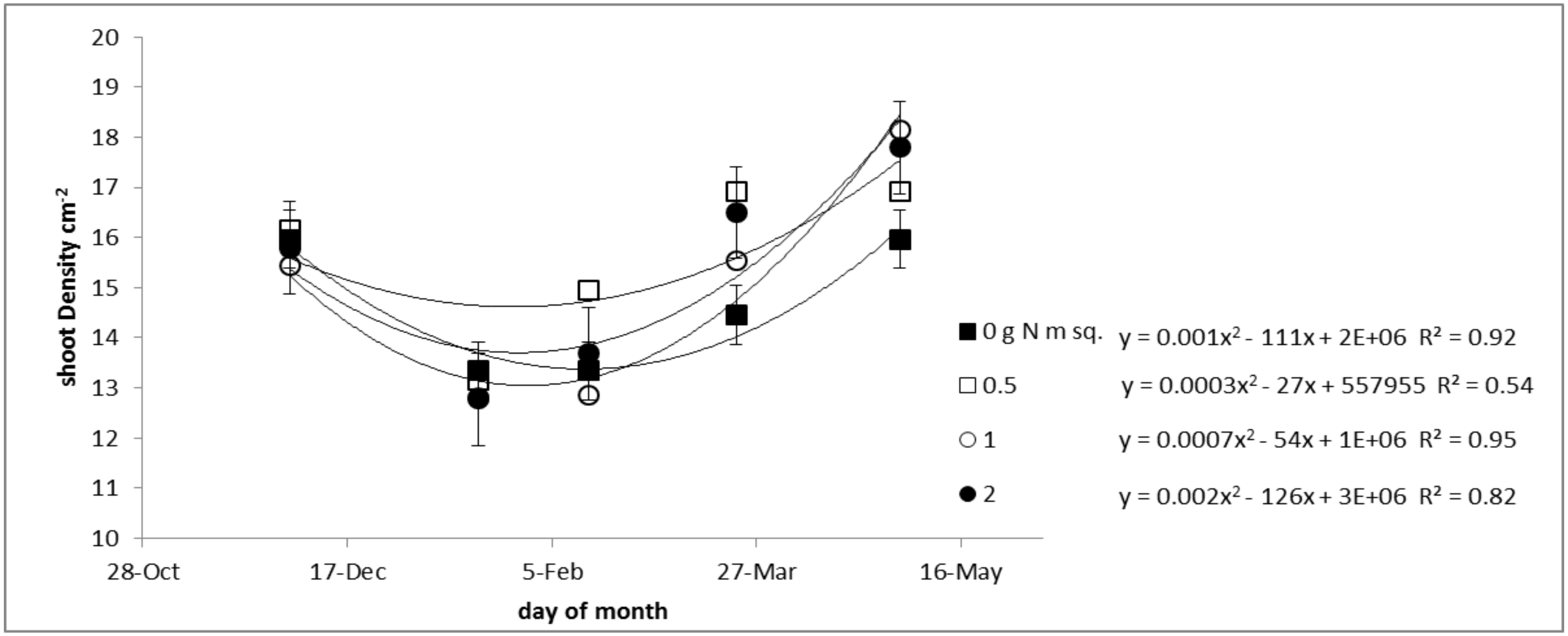

Figure 5. Relative color (1-9 visual scale, with a '1' = brown) of TifEagle hybrid bermudagrass (non-trafficked plots), by N rate and sampling date, 2012

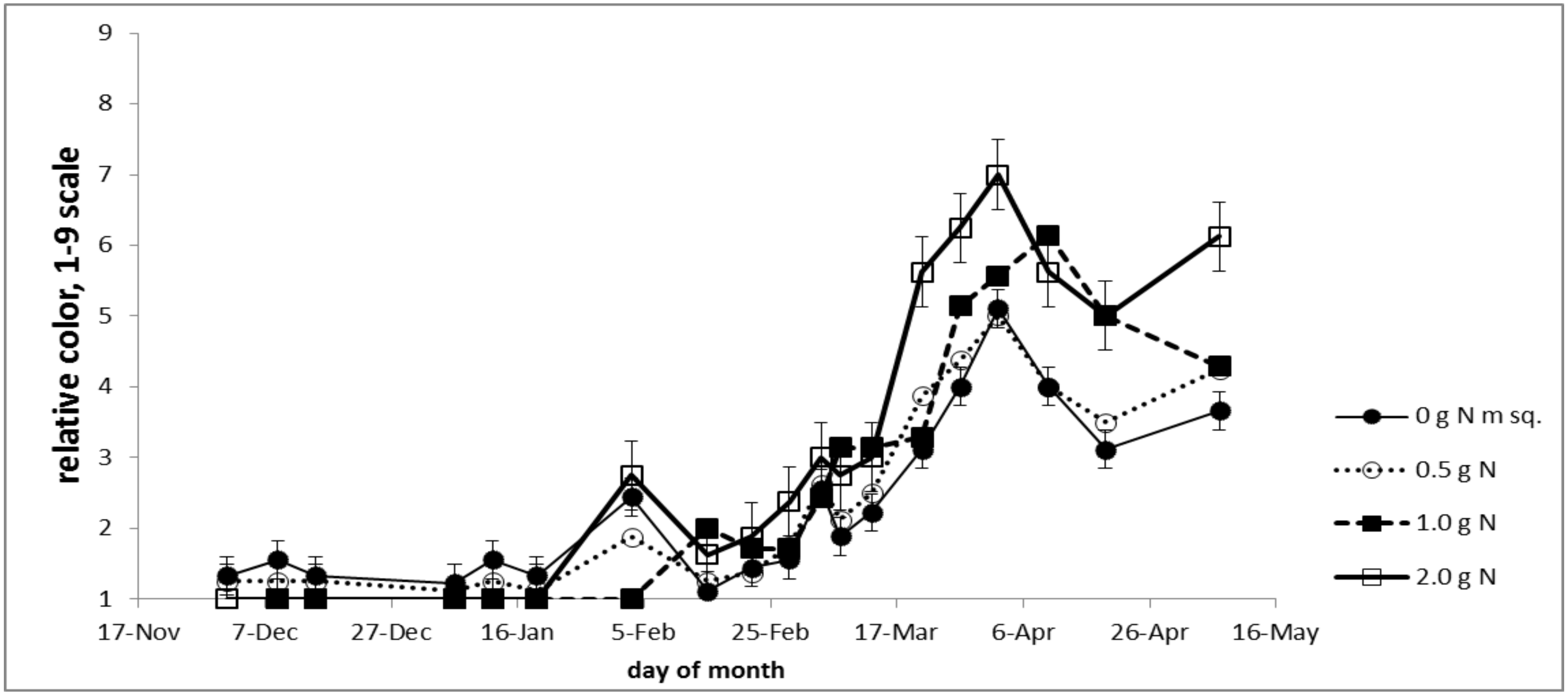

Figure 6. Relative color (1-9 visual scale, with a ‘1’ = brown) of TifEagle hybrid bermudagrass with (non-trafficked plots), by N rate and sampling date, 2013

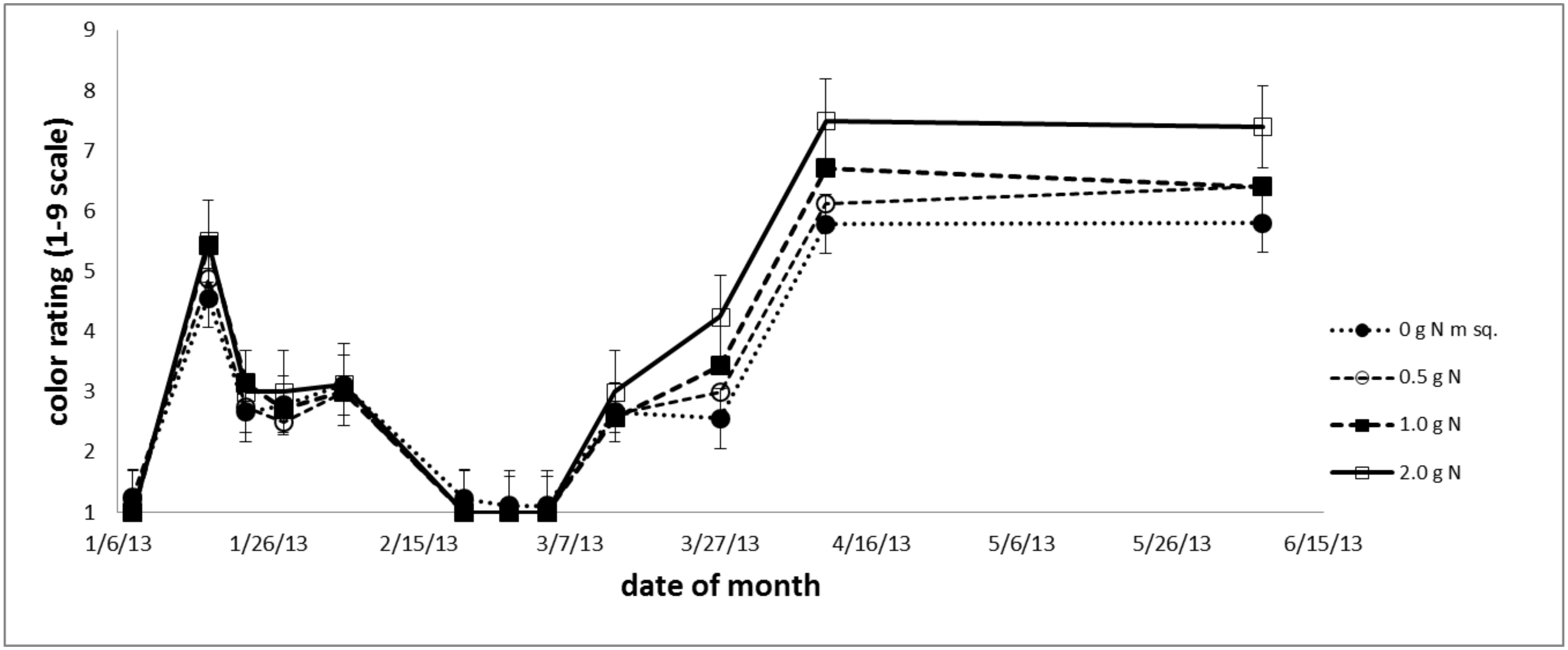

Figure 7. Relative color (1-9 visual scale, with a ‘1’ = brown) of TifEagle hybrid bermudagrass (trafficked plots), by N rate and sampling date, 2012

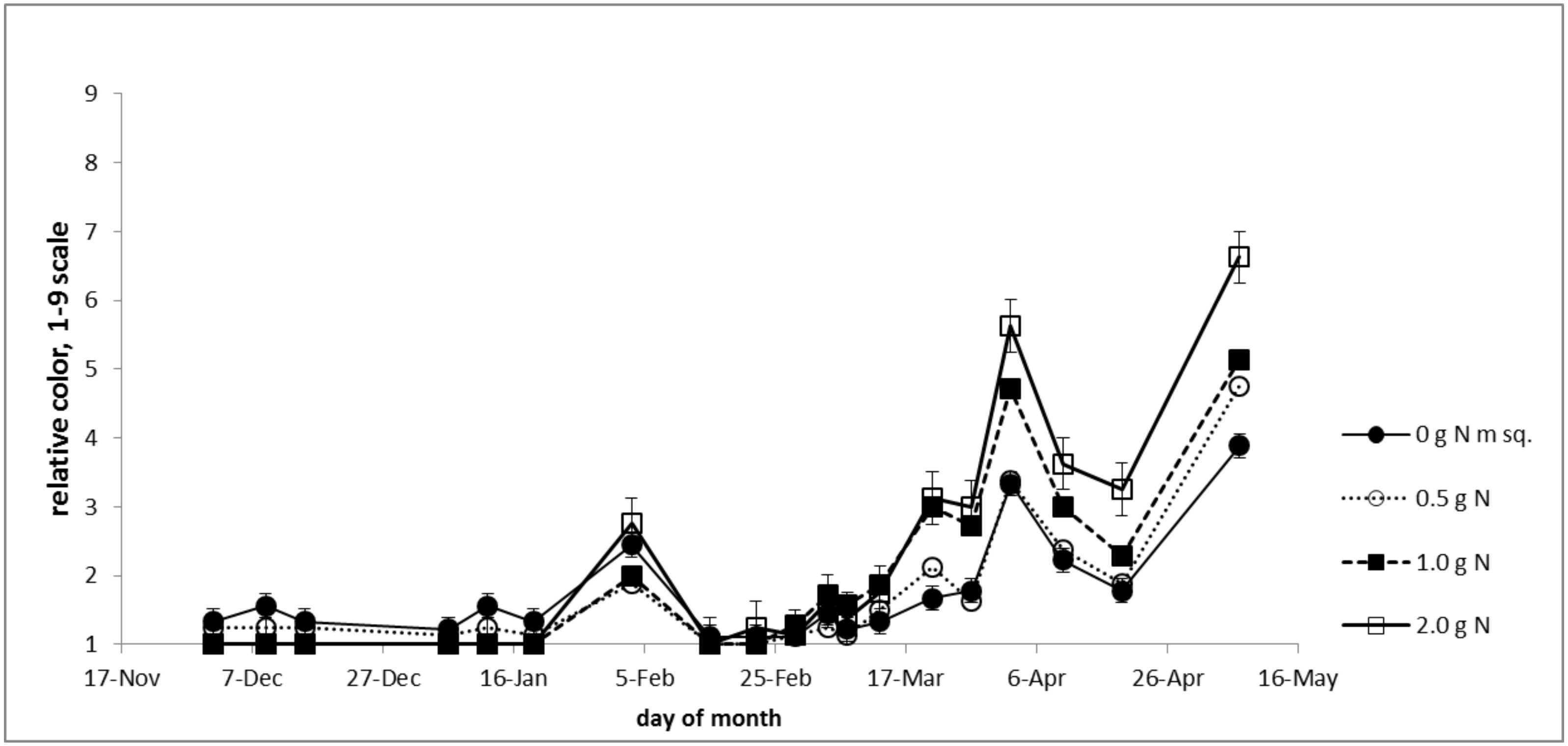

Figure 8. Relative color (1-9 visual scale, with a ‘1’ = brown) of TifEagle hybrid bermudagrass (trafficked plots), by N rate and sampling date, 2013

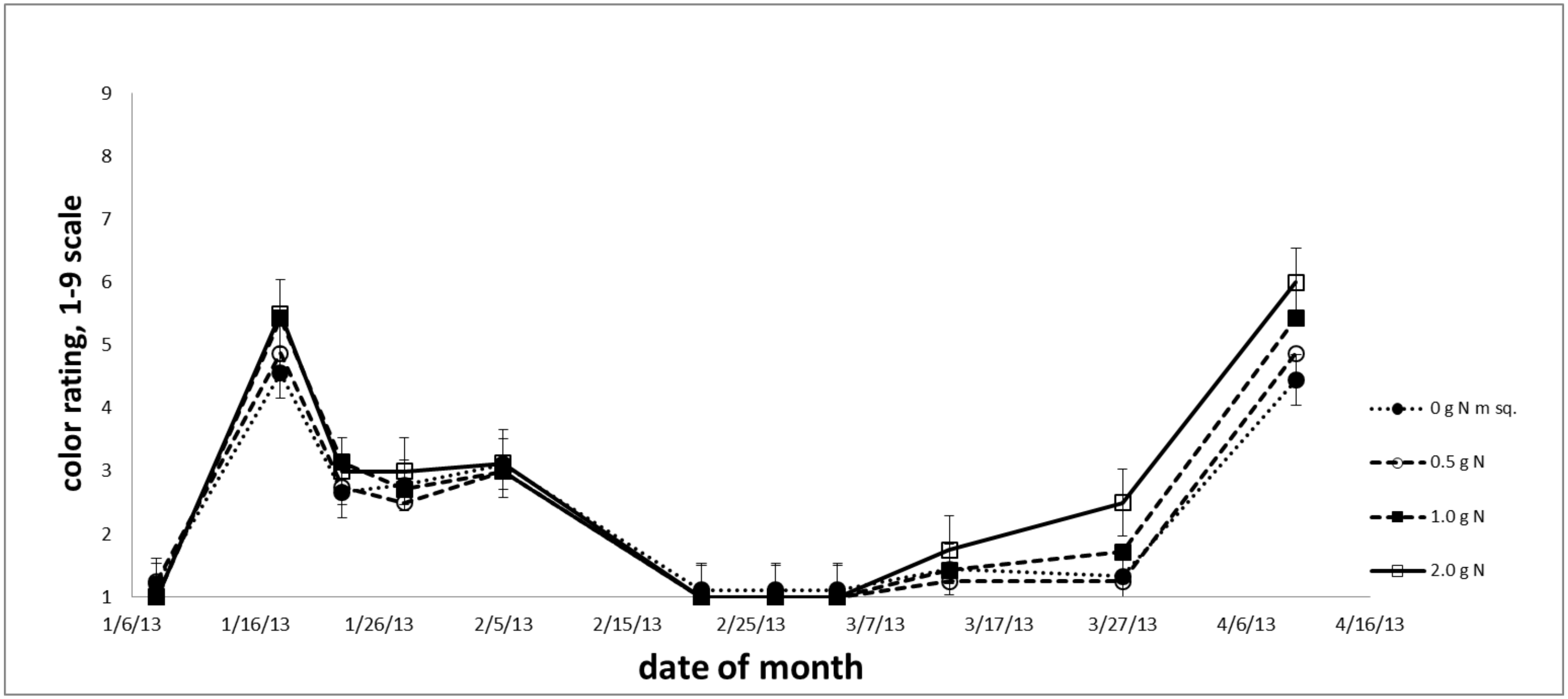

Figure 9. Relative color (1-9 visual scale, with a '1' = brown) of *Poa trivialis* on TifEagle hybrid bermudagrass (non-trafficked plots), by N rate and sampling date, 2012

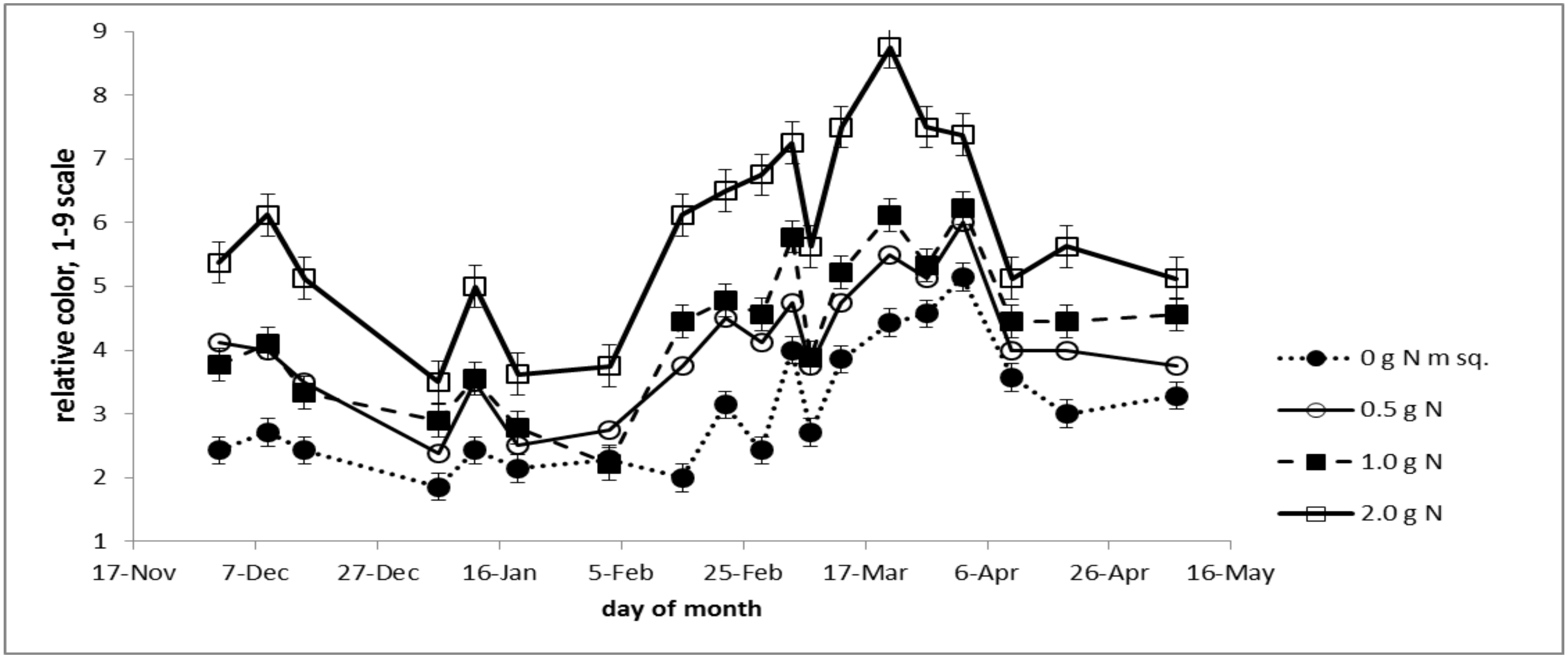

Figure 10. Relative color (1-9 visual scale, with a ‘1’ = brown) of *Poa trivialis* on TifEagle hybrid bermudagrass (non-trafficked), by N rate and sampling date, 2013

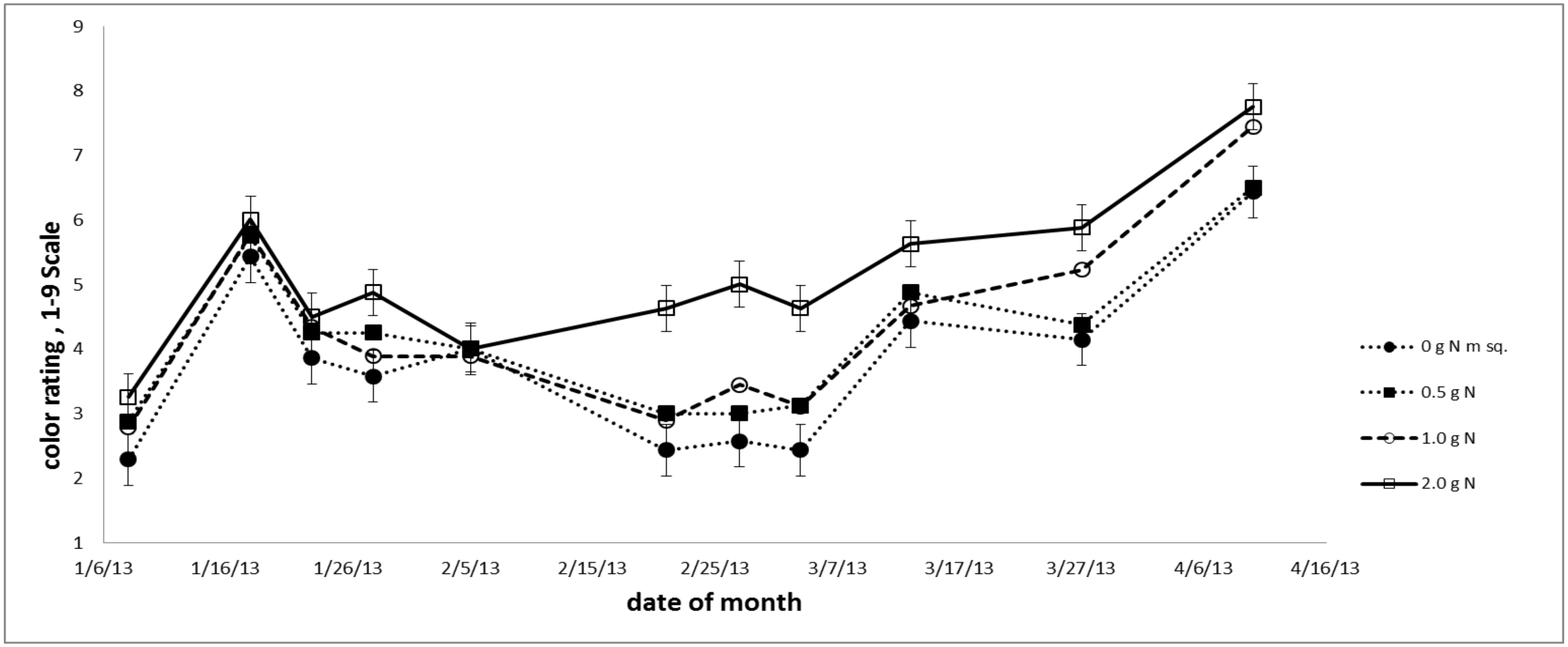

Figure 11. Relative color (1-9 visual scale, with a '1' = brown) of *Poa trivialis* on TifEagle hybrid bermudagrass (trafficked plots), by N rate and sampling date, 2012

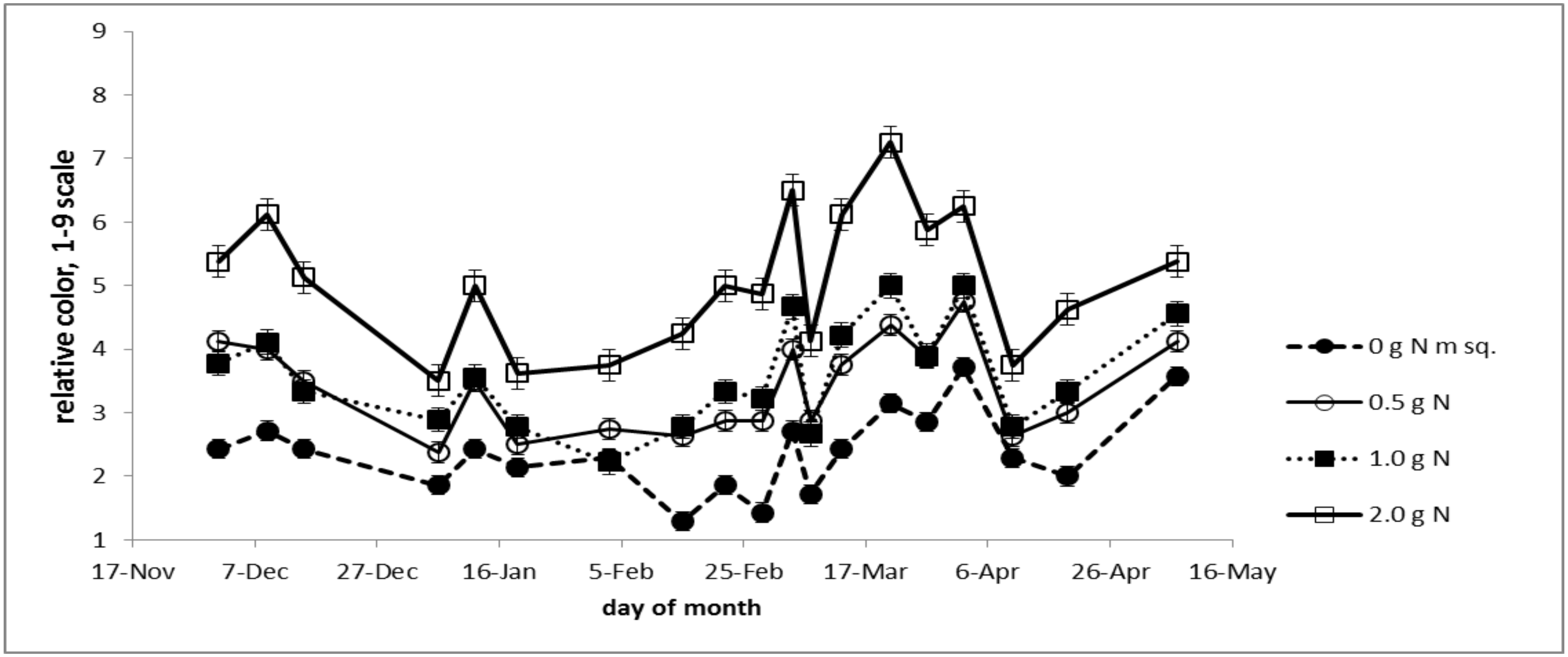

Figure 12. Relative color (1-9 visual scale, with a ‘1’ = brown) of *Poa trivialis* on TifEagle hybrid bermudagrass (trafficked), by N rate and sampling date, 2013

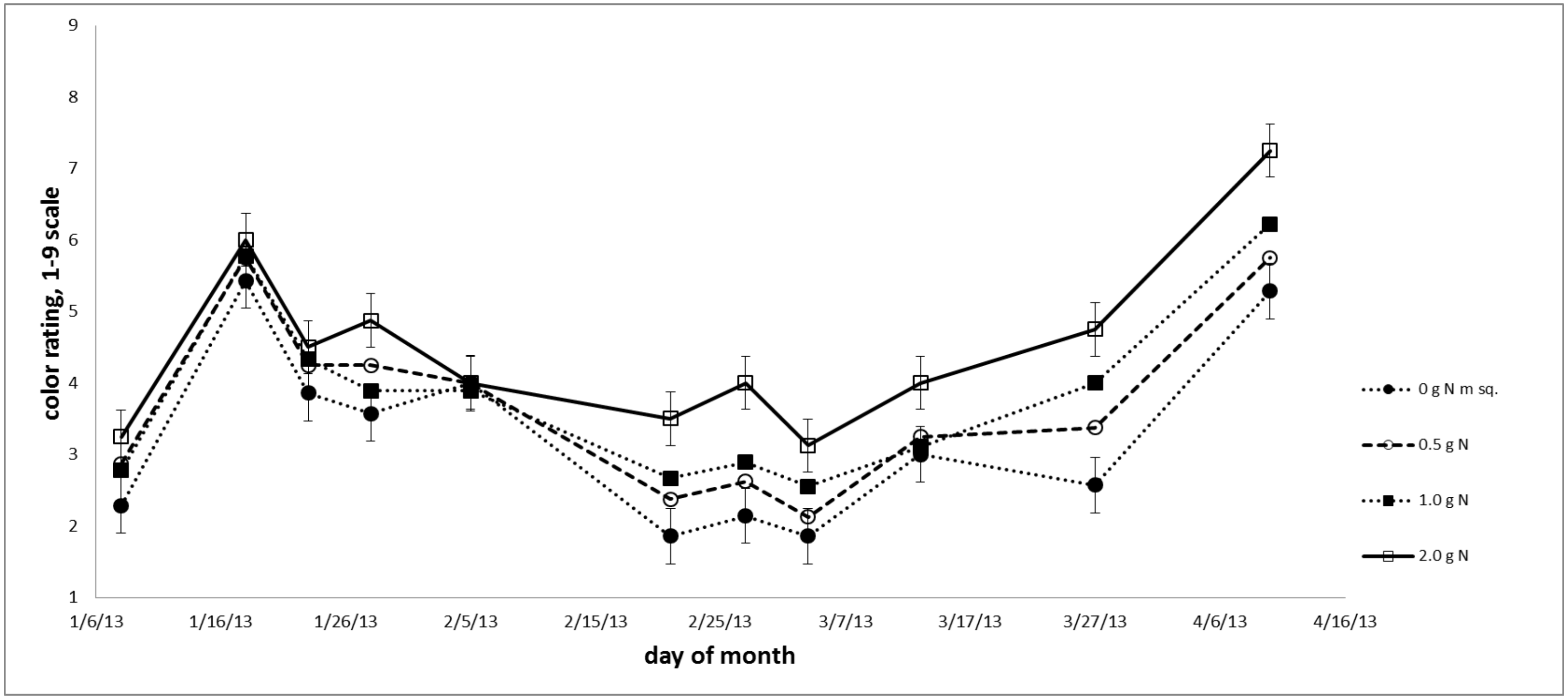

Figure 13. Relative quality (1-9 visual scale, with a '1' for dormant/dead turf) TifEagle hybrid bermudagrass (trafficked), by N rate and sampling date, 2012

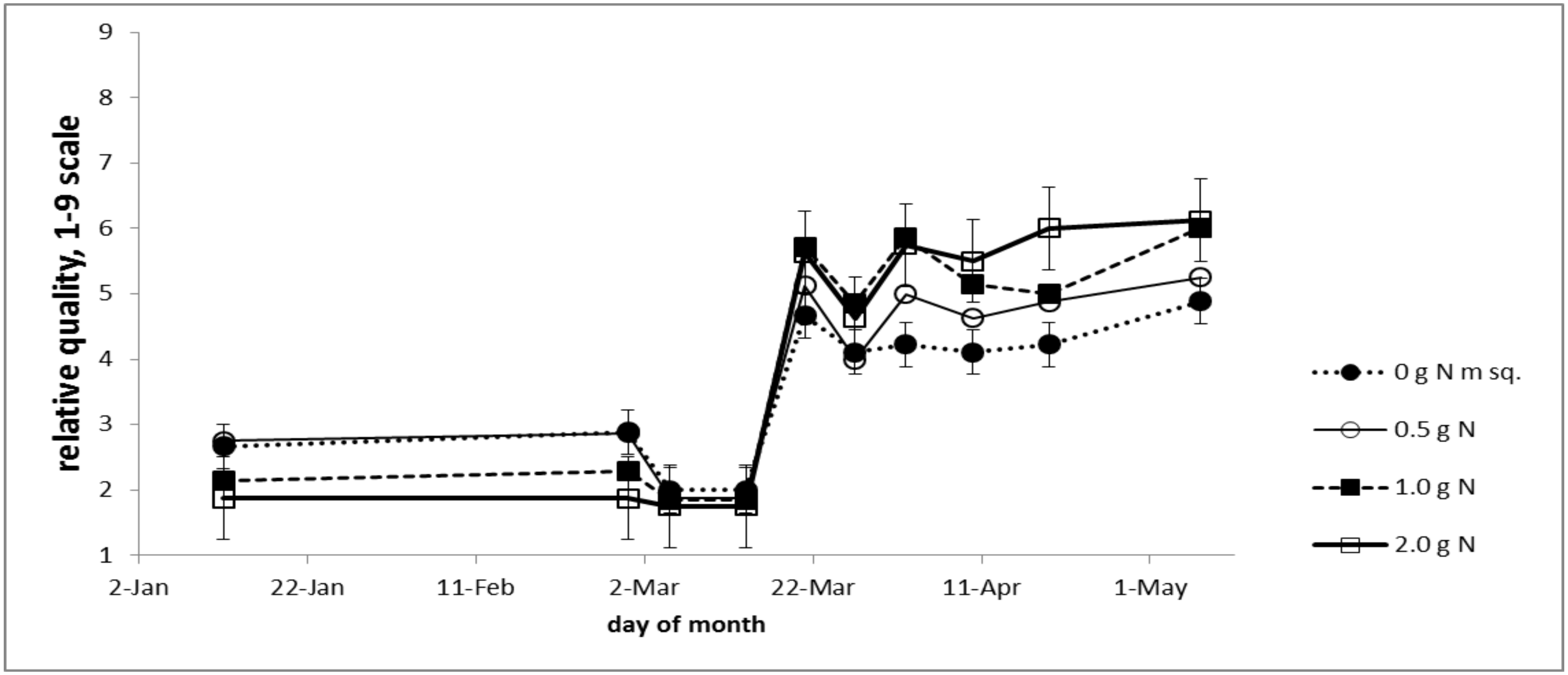

Figure 14. Relative quality (1-9 visual scale, with a '1' for dormant/dead turf) of TifEagle hybrid bermudagrass (non-trafficked plots), by N rate and sampling date, 2012

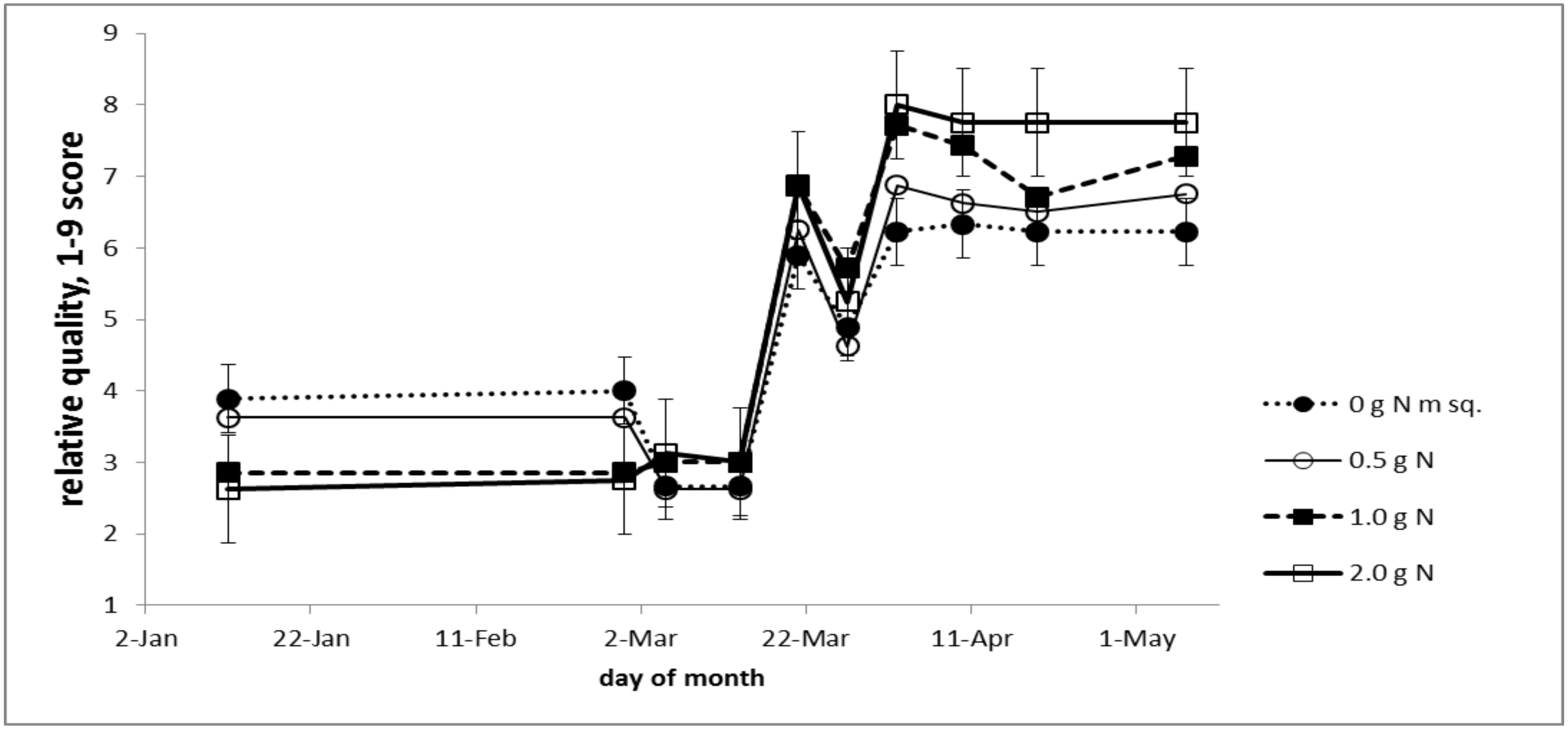

Figure 15. Relative quality (1-9 visual scale, with a '1' for dormant/dead turf) of TifEagle hybrid bermudagrass (non-trafficked plots), by N rate and sampling date, 2013

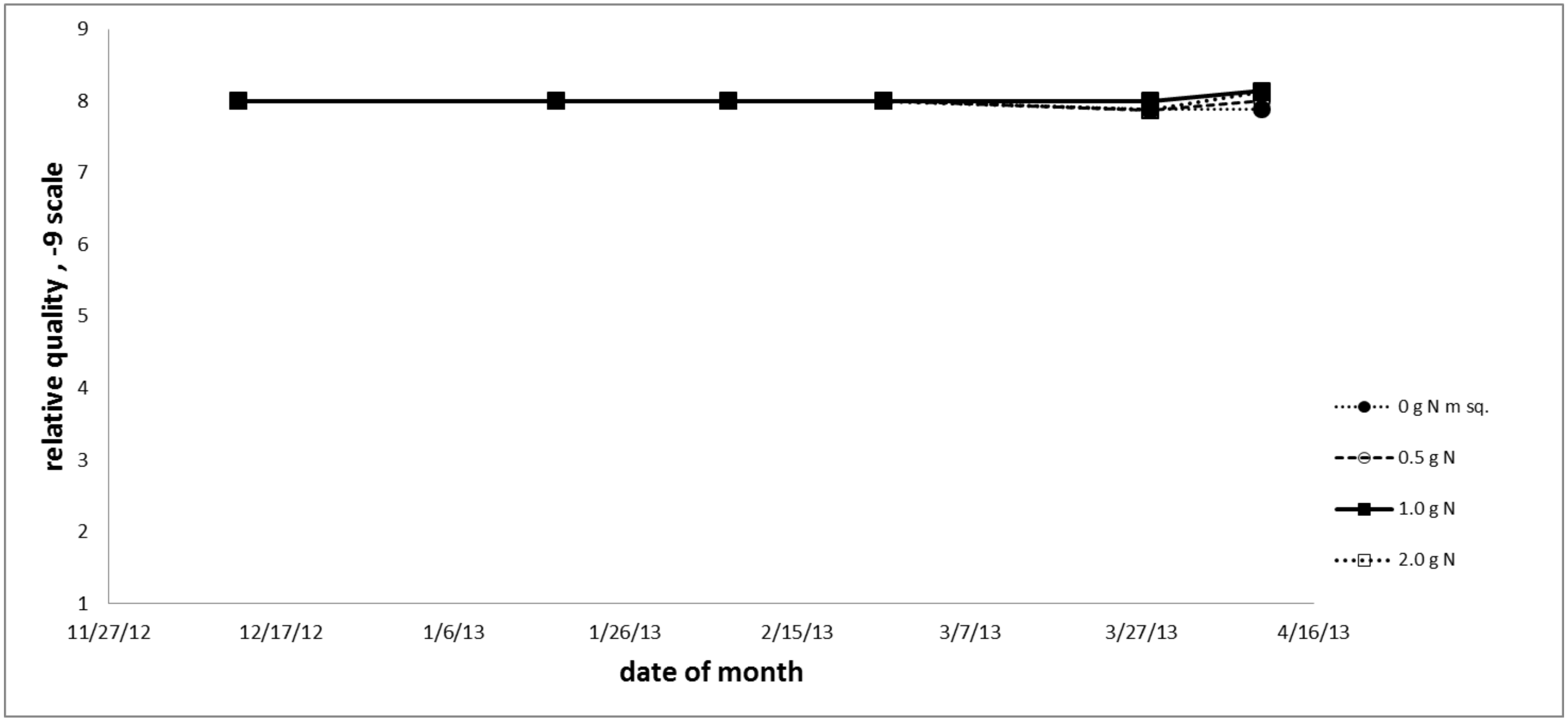

Figure 16. Relative quality (1-9 visual scale, with a '1' for dormant/dead turf) of TifEagle hybrid bermudagrass (trafficked), by N rate and sampling date, 2013

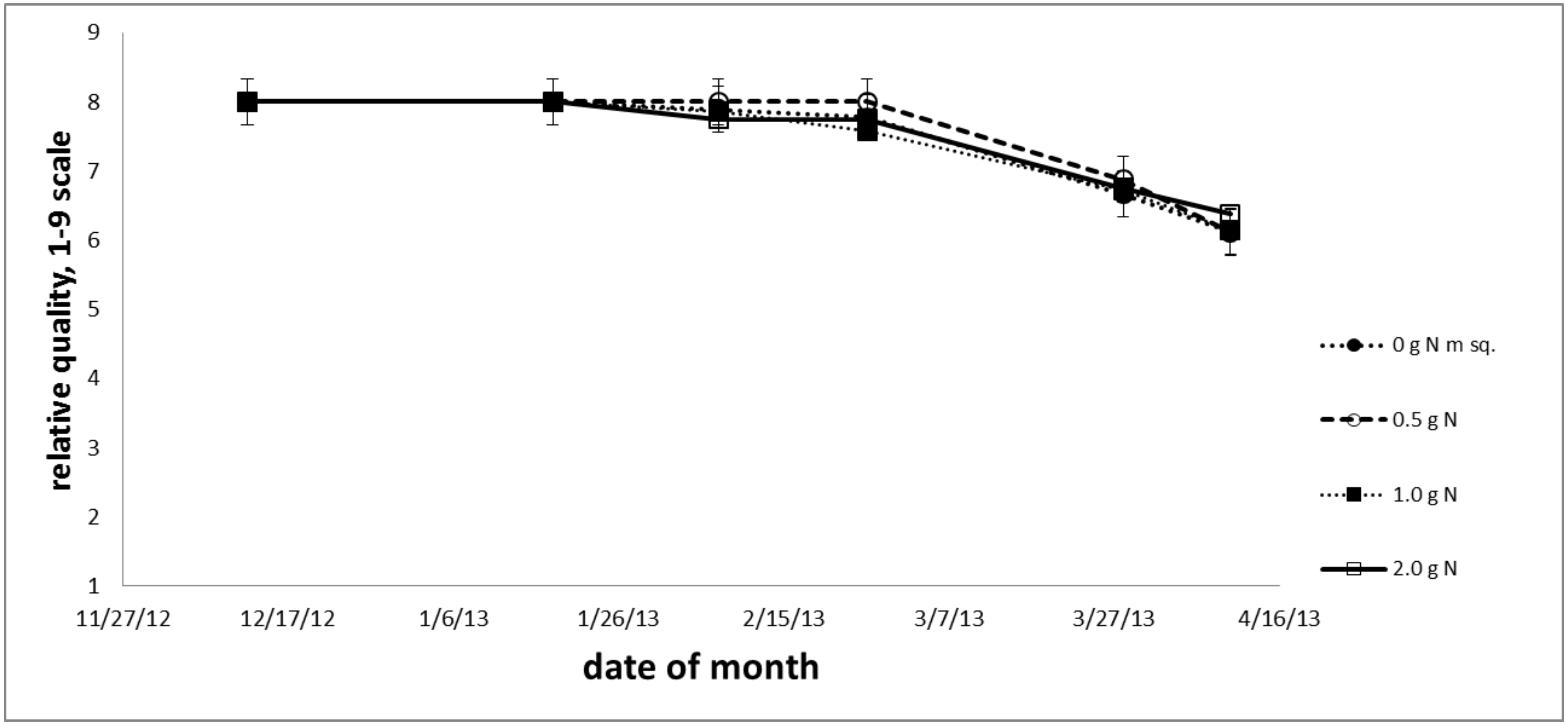

Figure 17. Relative quality (1-9 visual scale, with a '1' for dormant/dead turf) of *Poa trivialis* on TifEagle hybrid bermudagrass (non-trafficked plots), by N rate and sampling date, 2012

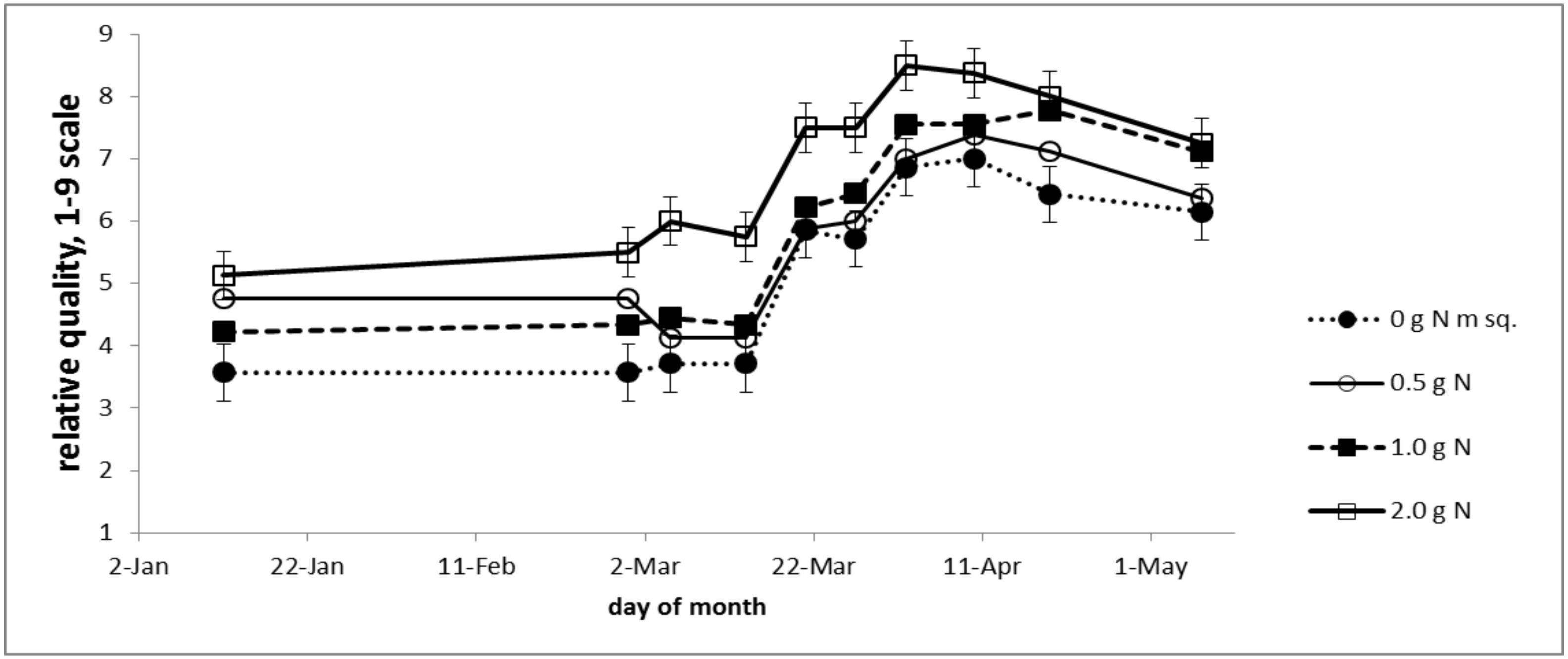

Figure 18. Relative quality of *Poa trivialis* on TifEagle hybrid bermudagrass (trafficked plots), by N rate and sampling date, 2012

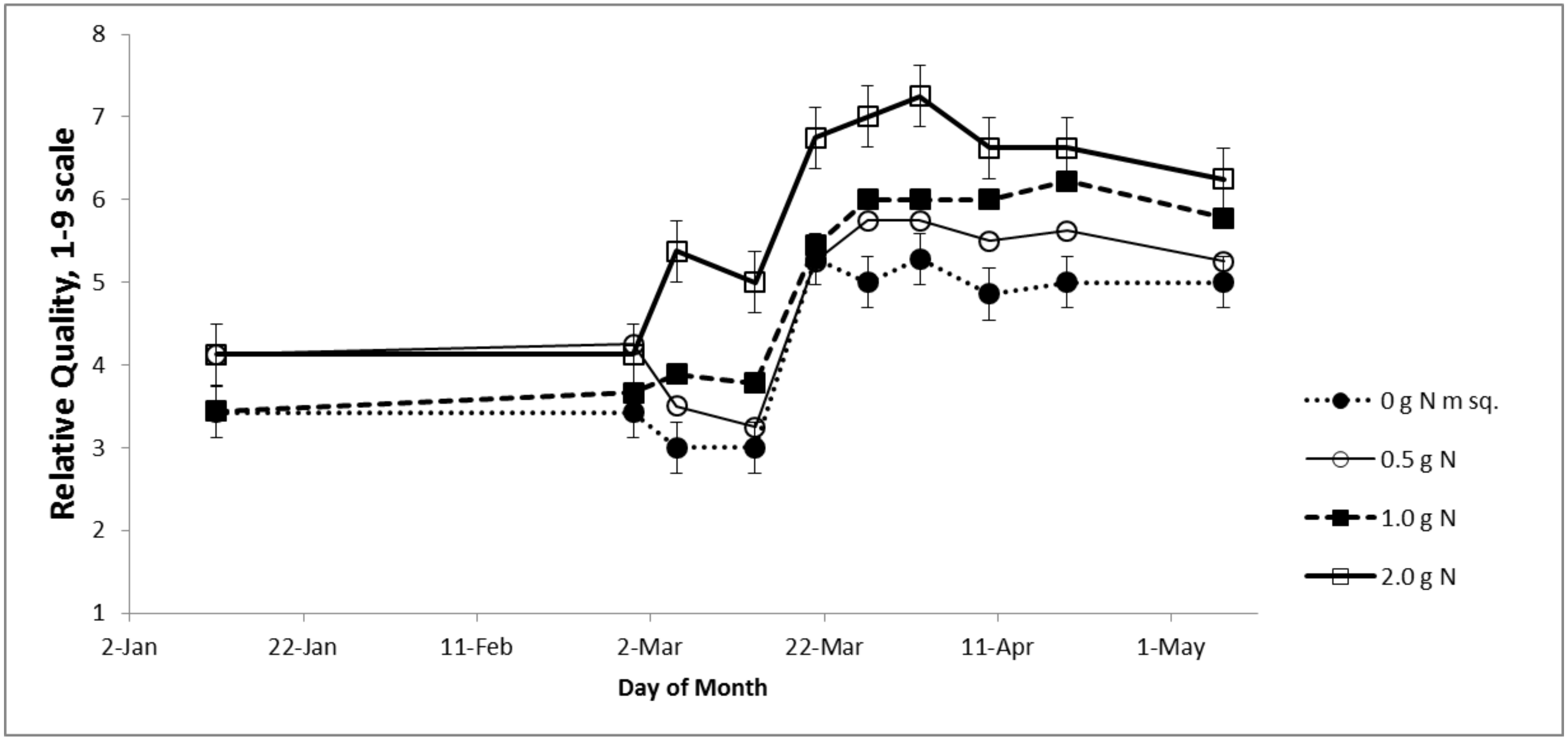

Figure 19. Relative quality (1-9 visual scale, with a ‘1’ for dormant/dead turf) of *Poa trivialis* on TifEagle hybrid bermudagrass (non-trafficked), by N rate and sampling date, 2013

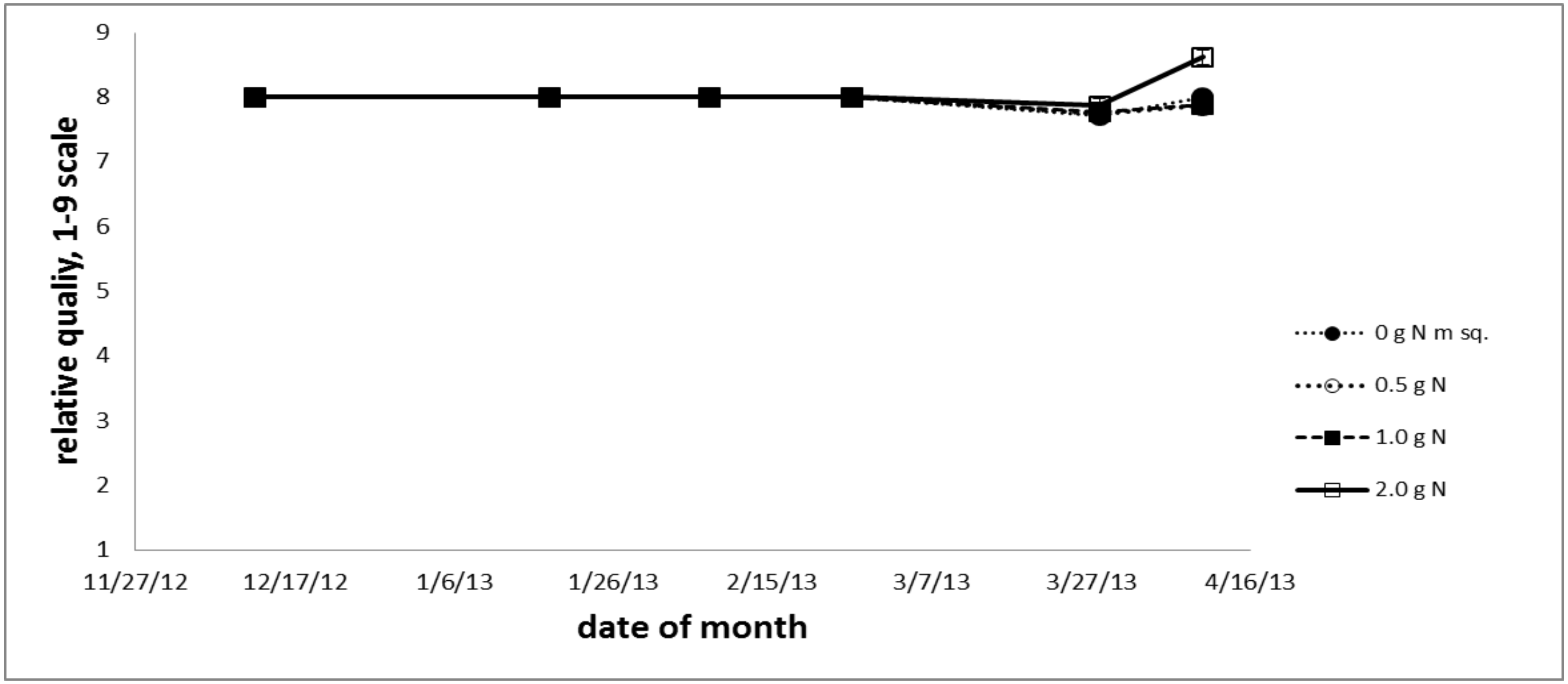

Figure 20. Relative quality (1-9 visual scale, with a ‘1’ for dormant/dead turf) of *Poa trivialis* on TifEagle hybrid bermudagrass (trafficked plots), by N rate and sampling date, 2013

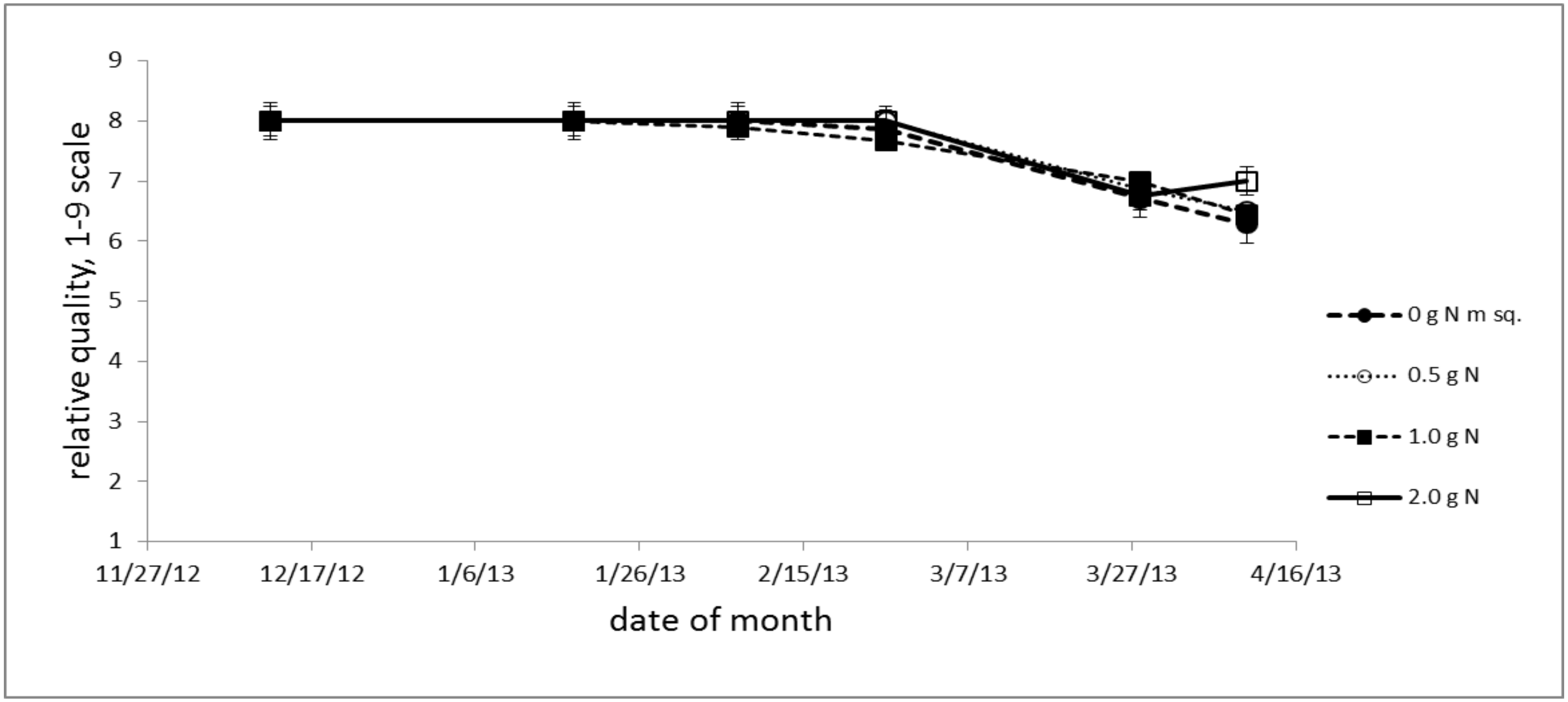

Figure 21. Effect of N rate (applied monthly) on *Poa trivialis* dry clipping yield, by sampling date, 2012

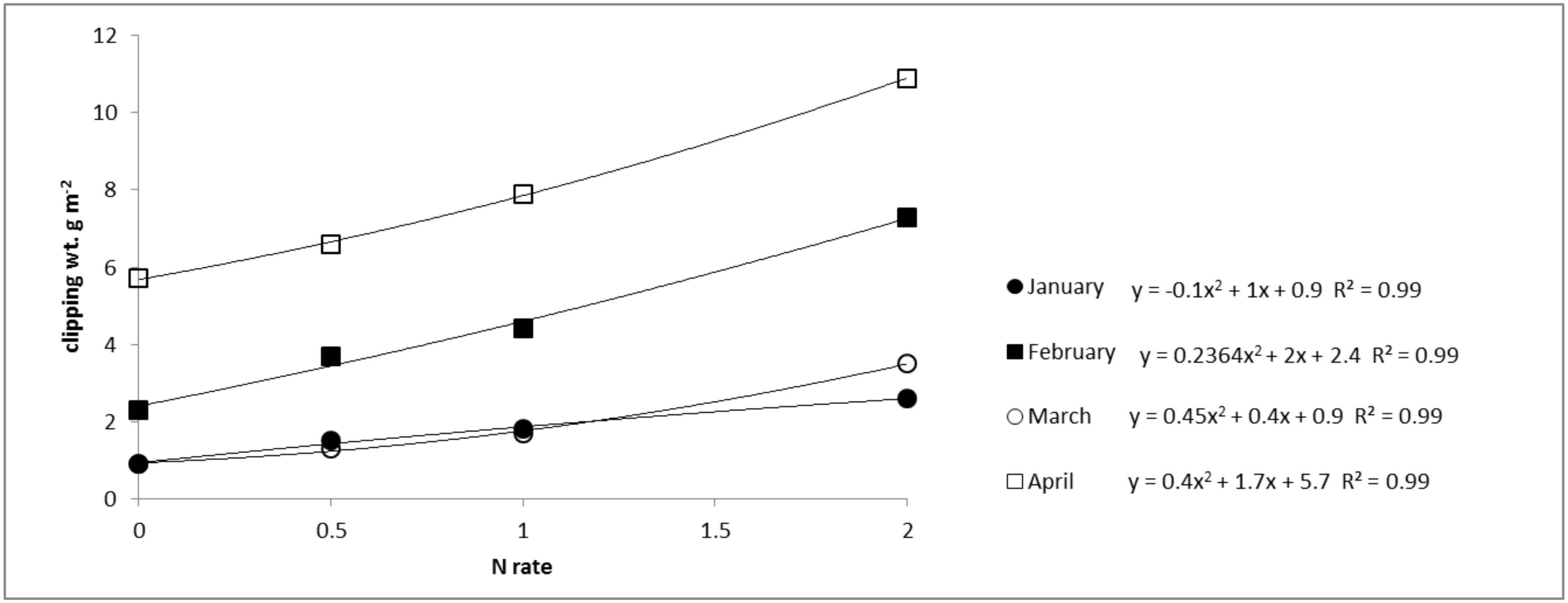

Figure 22. Effect of N rate (applied monthly) on *Poa trivialis* dry clipping yield, by sampling date, 2013

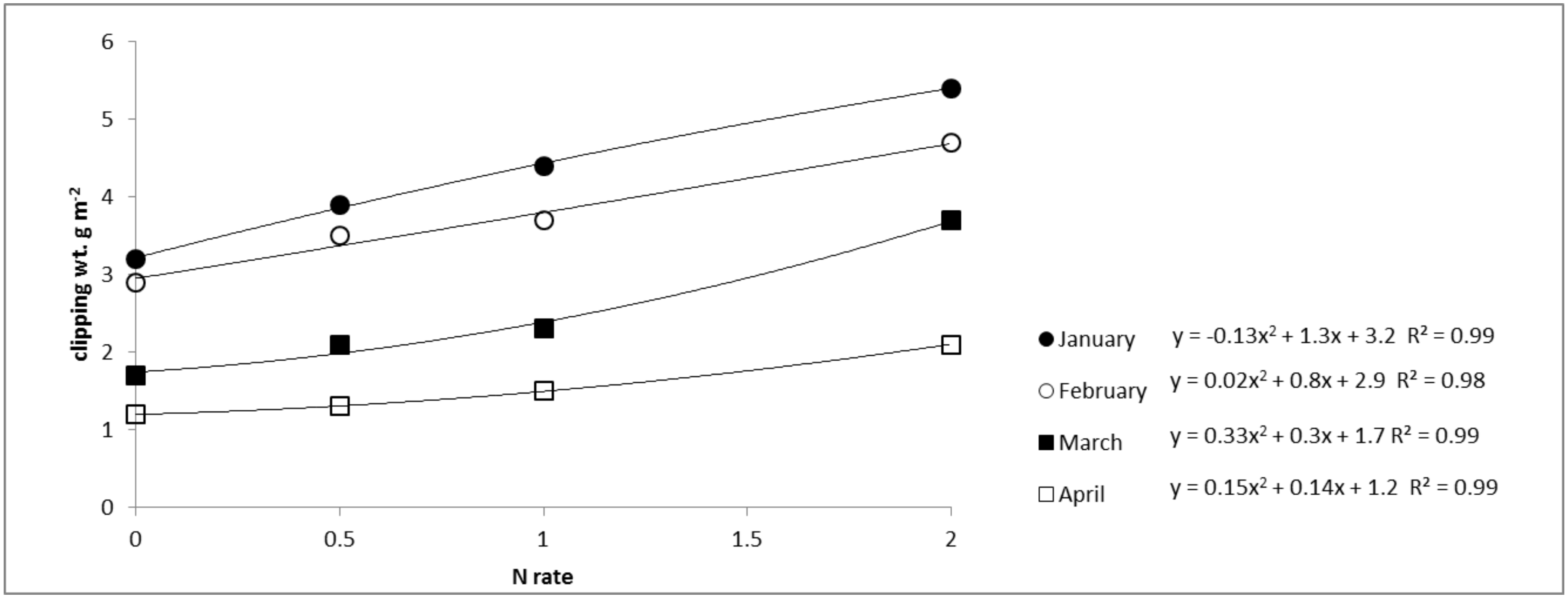

Figure 23. Relative quality of *P. trivialis* on a TifEagle hybrid bermudagrass (trafficked and non-trafficked plots), by sampling date, 2013

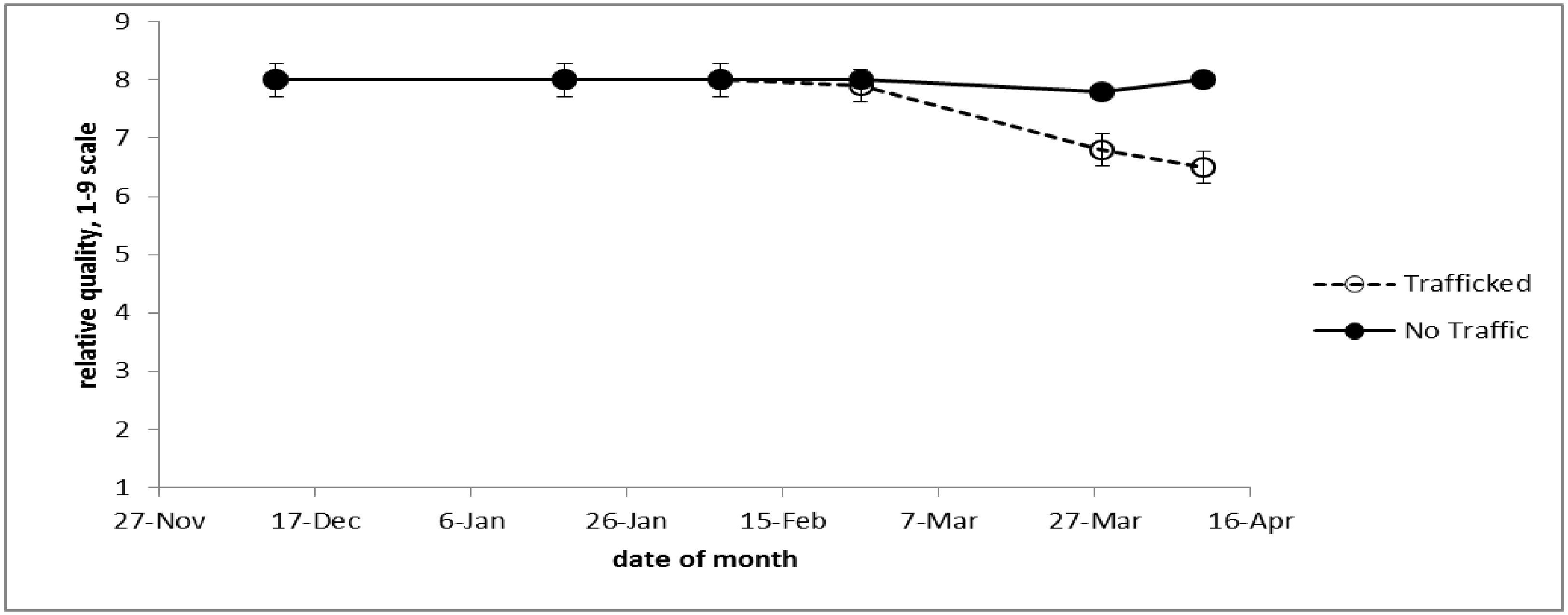

Figure 24. Relative quality of TifEagle hybrid bermudagrass (trafficked and non-trafficked) by sampling date, 2013

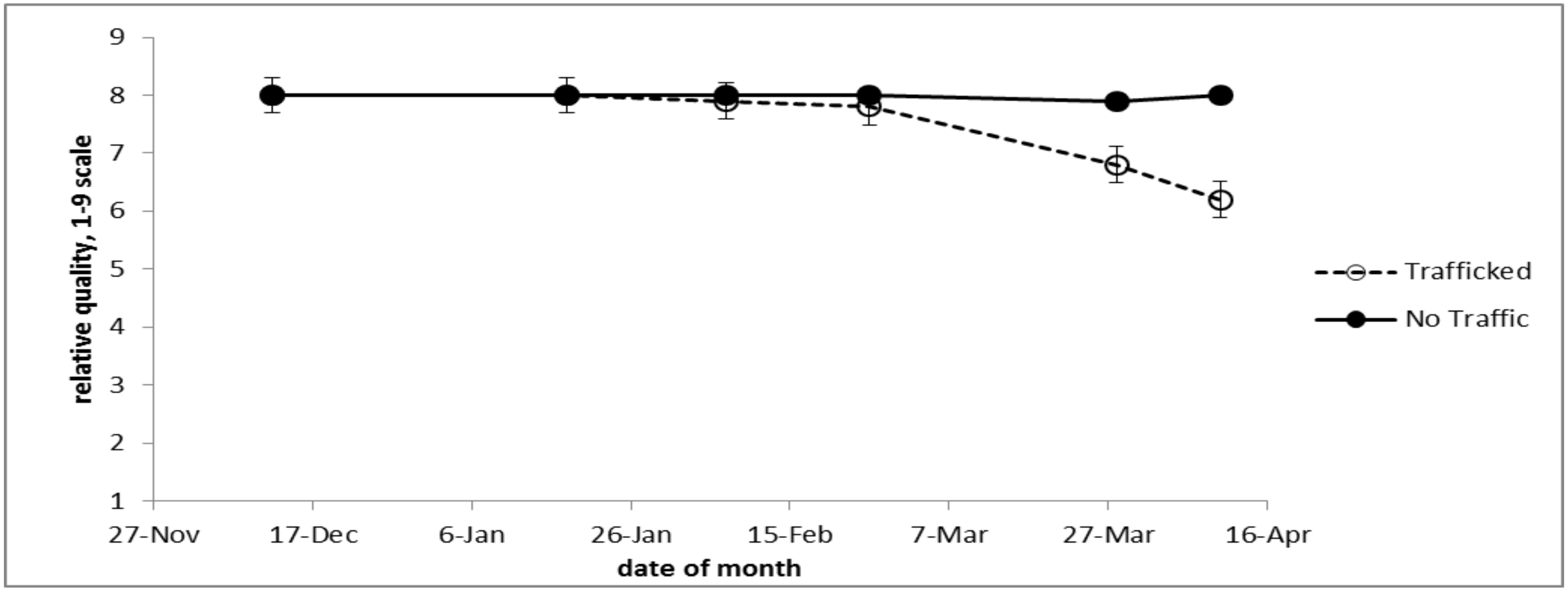

Figure 25. Relative quality of *P. trivialis* on a TifEagle hybrid bermudagrass (trafficked and non-trafficked) by sampling date, 2012

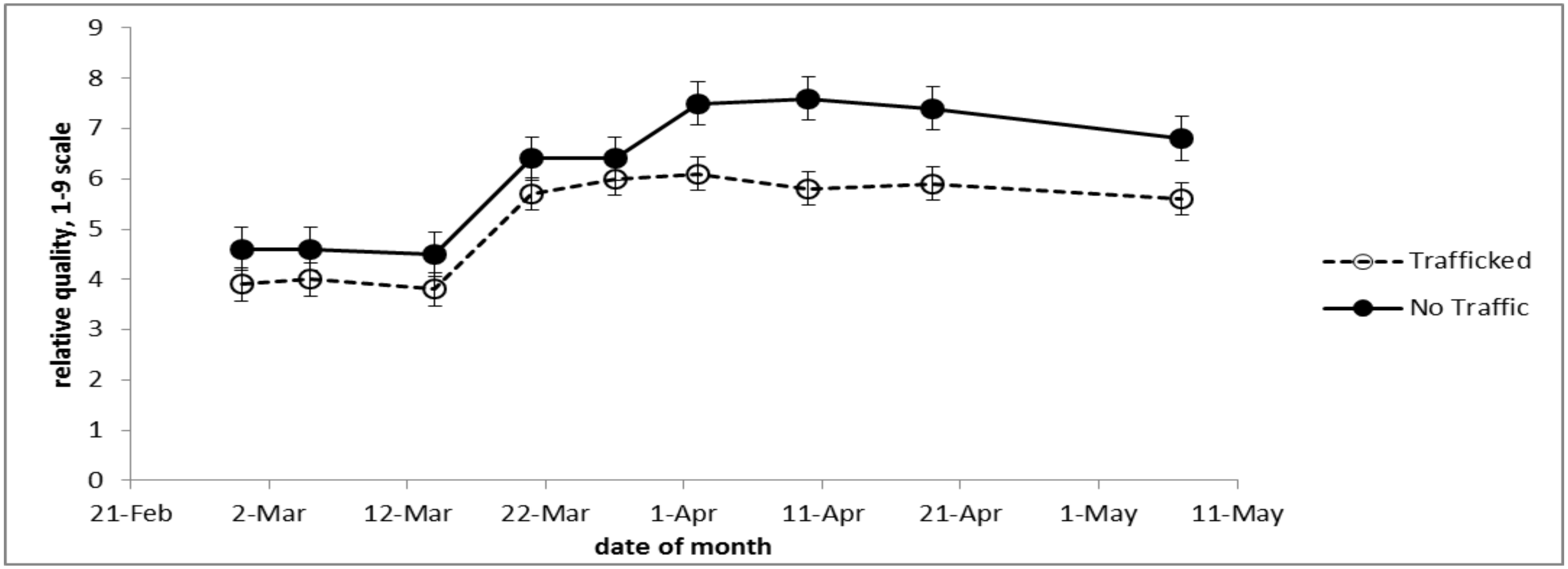

Figure 26. Relative quality of TifEagle hybrid bermudagrass (trafficked and non-trafficked) by sampling date, 2012

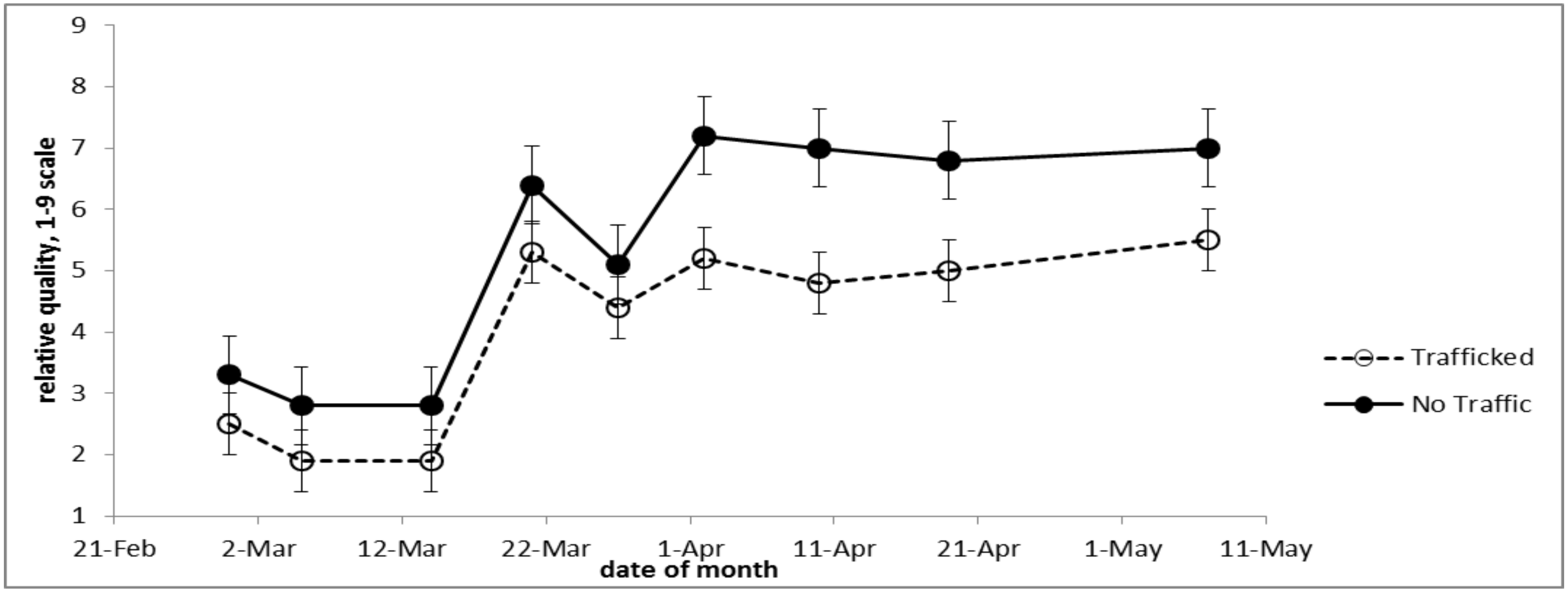

Figure 27. Relative color of TifEagle hybrid bermudagrass (trafficked and non-trafficked) by sampling date, 2013

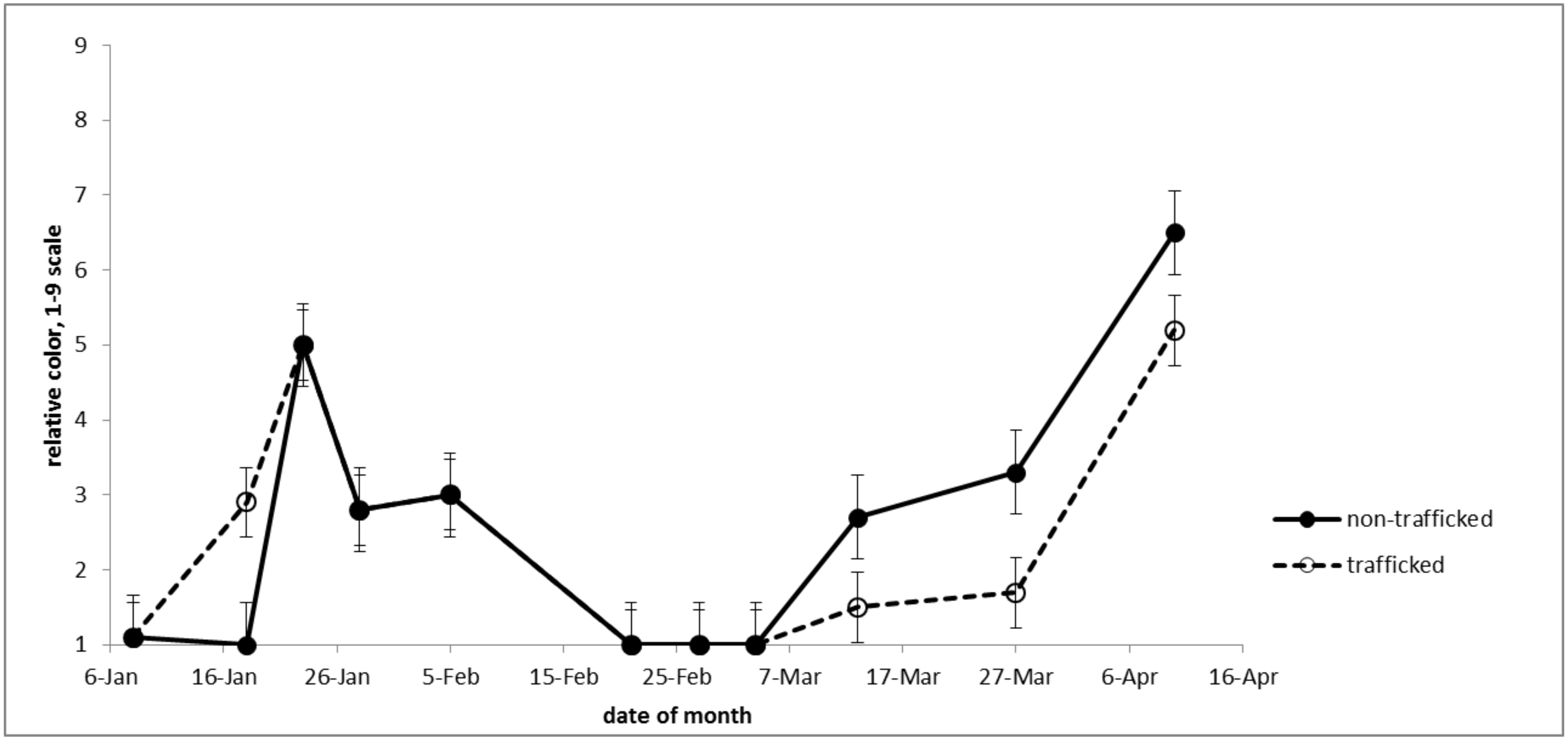

Figure 28. Relative color of *P. trivialis* on a TifEagle hybrid bermudagrass (trafficked and non-trafficked plots), by sampling date, 2013

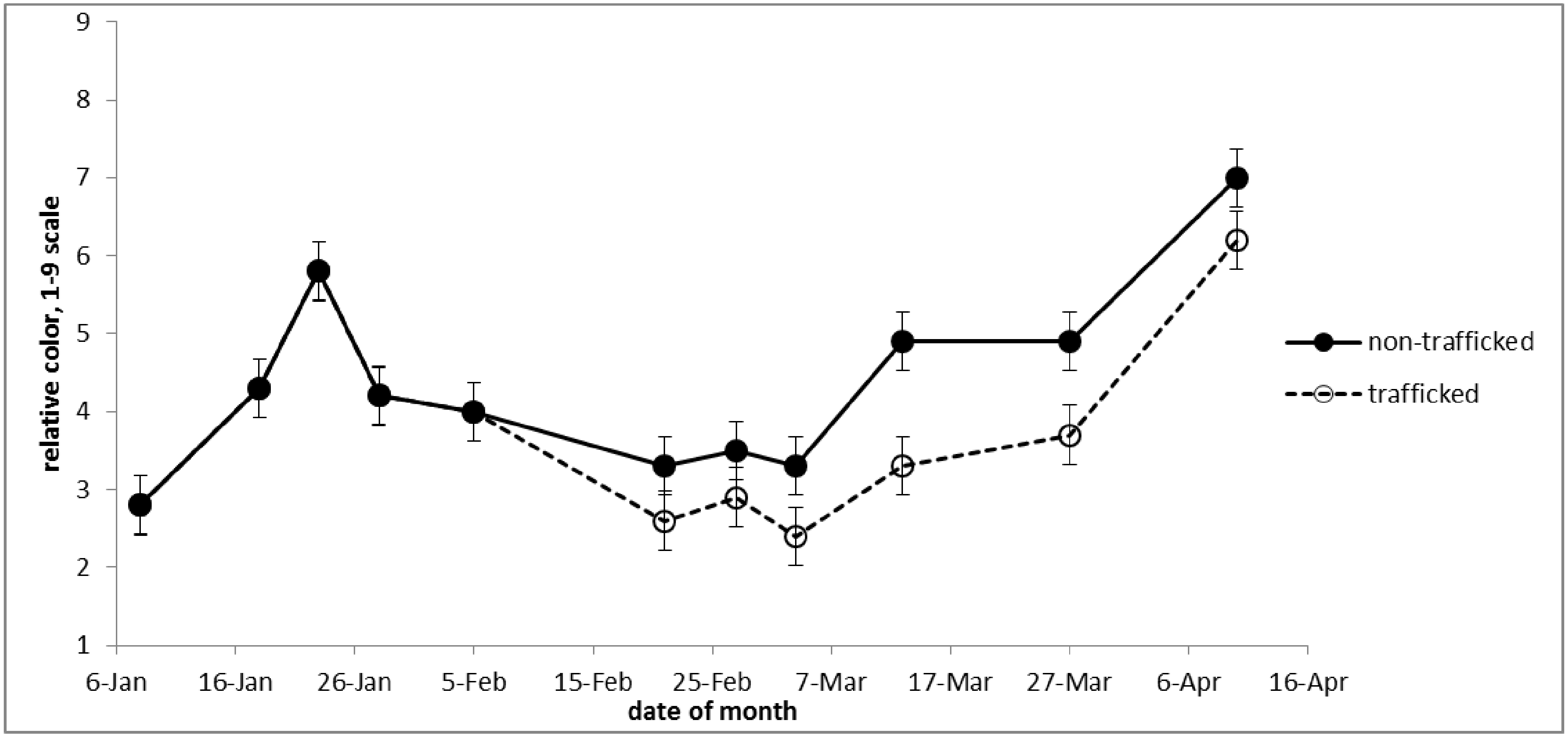

Figure 29. Relative color of TifEagle hybrid bermudagrass (trafficked and non-trafficked) by sampling date, 2012

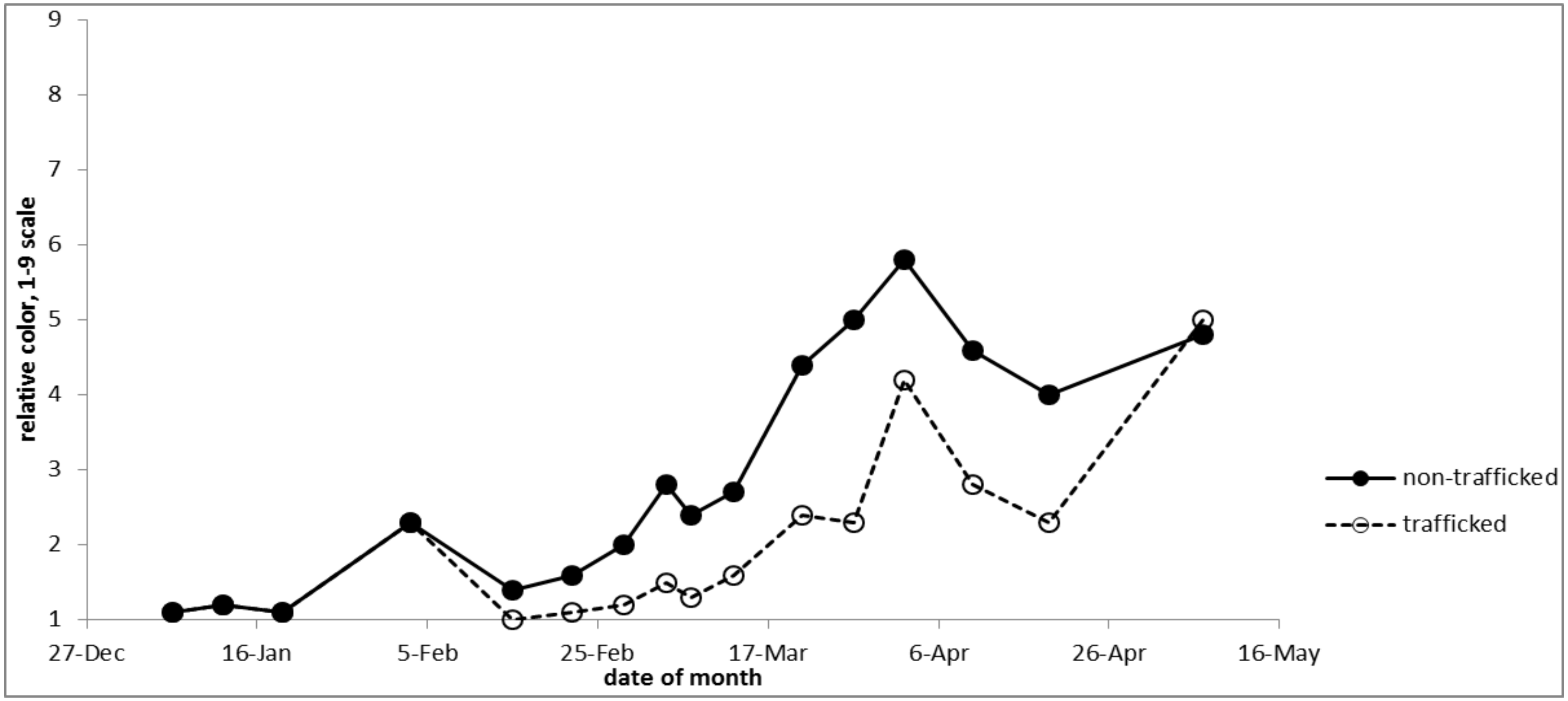

Figure 30. Relative color of *P. trivialis* on a TifEagle hybrid bermudagrass (trafficked and non-trafficked plots), by sampling date, 2012