Europ. J. Agronomy 37 (2012) 23–30

Contents lists available at SciVerse ScienceDirect

European Journal of Agronomy

journal homepage: www.elsevier.com/locate/eja

Nitrogen remote diagnosis in a creeping bentgrass golf green

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ARTICLE INFO

Article history:
Received 15 August 2011
Received in revised form 14 October 2011
Accepted 17 October 2011

Keywords:
Turfgrass
Putting green
Green speed
Bermudagrass
Precision agriculture
Normalized difference vegetation index (NDVI)
Algorithm

ABSTRACT

Nitrogen fertilization is a key factor of the aesthetics and playability for golf greens. Nitrogen fertilization management is based on predetermined scheduled applications, set rates, or expected improvement in visual quality and green speed. As a consequence, the objective of this study was to obtain seasonal N application models (algorithms) based on remote sensing, optimizing playability and aesthetic quality. A 3-yr field study under Mediterranean conditions was conducted on an experimental 'L-93' creeping bentgrass (*Agrostis stolonifera* L.) USGA green, to examine effects of seasonal N fertilizer rates on color, clipping yields, and ball roll (green speed). The remote sensors used were a digital camera and reflectance meter (FieldScout CM1000 Chlorophyll Meter). From digital photographs, a dark green color index (DGCI) was calculated. All data were normalized (relative). For all seasons, a third-order polynomial response model was the best when using a CM1000 and a digital camera. Clipping yields and ball roll regressions were linear, increasing and decreasing when the N fertilizer rate increased, respectively. Ball roll and clipping relative values were correlated with both sensors. To fit a seasonal optimum N fertilizer rate model as a function of remote sensors and the other measured parameters, the intersection of models obtained from relative values of CM1000 and digital camera with ball roll and clipping was calculated, but ball roll was considered the most suitable. The model of the digital camera with automatic settings was less accurate and underestimated the optimum N rate. However, because the actual values of digital camera and CM1000 were correlated, converting DGCI values and applying CM1000 models enabled the obtaining of practically the same N fertilizer applications. A practical application procedure of these seasonal models for an entire golf course was also shown. Actual N recommendation applications with a quick remote diagnosis (CM1000) for creeping bentgrass golf green are feasible under similar management practices in Mediterranean environments. A digital camera can also be used successfully, but it should be better when its analysis is based on CM1000 models.

1. Introduction

Of the essential nutrients, N is required in the greatest quantity and generally influences the golf course's green quality and growth rate most significantly (Schlossberg and Schmidt, 2007), alleviating the stress due to intensive maintenance and use (Trenholm et al., 2000). Under optimal growing conditions, N promotes a high-quality shoot density, color, and uniformity (aesthetic quality), vigour (Waddington et al., 1978), root-to-shoot ratios (Schlossberg and Karnok, 2001), recovery from damage, and overall health (Davis and Dernoeden, 2002). Nevertheless, in the same way that poor N fertilization prevents a high quality green, N over-fertilization may cause undesirable effects on green quality. Nitrogen over-fertilization increases unnecessary clipping yields and thatch (Barton and Colmer, 2006; Pease et al., 2011). Davis and Dernoeden (2002), Fu et al. (2009), and López-Bellido et al. (2010) indicated that N fertilization can increase organic matter levels in the upper 2.5 cm soil zone. According to McCarty et al. (2007), Callahan et al. (1998), and Carley et al. (2011), excessive thatch-mat layers (organic matter) in greens, and the limiting of permeability, represent one of the most difficult problems in green management. In addition, creeping bentgrass stems and roots become elevated in thick surface organic layers, and plants can be rendered more susceptible to injury from diseases and summer stresses (Turgeon, 2008). Another negative effect of over-fertilization is related to playability: ball roll distances, i.e., green speed, decrease as N fertilizer rate increases (Streich et al., 2005; Pease et al., 2011). Finally, nitrate leaching through sand-based golf greens, which have a low capacity to retain

Abbreviations: DGCI, dark green color index; SI, sufficiency index.

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doi:10.1016/j.eja.2011.10.001

nutrients and water, can be of particular concern when considering surface and groundwater pollution (Brown, 1982; Petrovic, 1990; Quiroga-Garza et al., 2001; Keskin et al., 2004; Paré et al., 2008).

In most cases, N fertilization is based on predetermined scheduled applications, set rates, or expected improvement in aesthetic quality (Mangiafico and Guillard, 2007) based on a visual examination and on the ball roll distance measured by a stimpmeter. The classic methods to determine the N application rate have usually been either soil samples or plant tissue analysis. However, these techniques require many samples, leading to excessive labor, time, and cost (Keskin et al., 2004); furthermore, data obtained have never been translated into actual N recommendation applications. These disadvantages have reinforced that many superintendents decide on a strict N fertilization program based on previous experience and intuition. This type of management can result in over-fertilization (Mangiafico and Guillard, 2007), and, as a consequence, the negative effects aforementioned can appear, or a suboptimal N fertilization that could affect turfgrass performance negatively to shoot density, associated with wear tolerance, and color (Johnson et al., 2003; Samaranayake et al., 2008). All the same, the superintendents have a margin between excessive and poor N fertilization where they have been working based on their experience, in many cases with success.

In recent years, new techniques to determinate turfgrass N status have arisen, such as the use of colorimeters (Landschoot and Mancino, 2000), measuring soil nitrate with anion exchange membranes (Mangiafico and Guillard, 2007), digital photography (Karcher and Richardson, 2003), and assessing turf color with reflectance meters (Keskin et al., 2004; Bell et al., 2002; Kruse et al., 2006; Xiong et al., 2007; Mangiafico and Guillard, 2007; Pease et al., 2011). These new technologies can quickly and inexpensively determine the N available by indirect measures related to N content (Keskin et al., 2004) in comparison with classical methods. However, some technologies are quicker and more accurate than others. The colorimeter is somewhat more time consuming to use because it requires the clipping of leaf blades, arranging them into a stack, taking a measurement, and then repeating the process (Mangiafico and Guillard, 2005). Moreover, Karcher and Richardson (2003) pointed out that measurement area is relatively small (<20 cm^2) and in the absence of uniform surface conditions, numerous subsample measurements would be necessary to accurately represent the color of turfgrass. Digital images quantify turf coverage and color with increased precision over more traditional evaluation methods on a relatively large turfgrass canopy (Richardson, 2001; Karcher and Richardson, 2003). However, digital camera requires more time than reflectance meters because of a subsequent image analysis with software to calculate the dark green color index (DGCI), even though Karcher and Richardson (2005) have developed a batch analysis of digital images to make the process easier.

Mangiafico and Guillard (2005, 2007) suggested that reflectance meters may be the best tool to guide the optimum N fertilization of turfgrass, featuring reduced sampling time (Kruse et al., 2006). Correlations between reflectance meter measurements and visual color, visual quality, shoot density, tissue N content, clipping, or chlorophyll concentration have been found in turfgrasses (Trenholm, 1999; Rodriguez and Miller, 2000; Bell et al., 2002; Keskin et al., 2004; Kruse et al., 2006; Mangiafico and Guillard, 2005, 2006, 2007; Bremer et al., 2011), confirming that a remote sensing system can reliably guide N fertilization. However, the information provided by these sensors is unfortunately biased by factors other than N (species, cultivar, soil, water supply, mowing, disease, wear, traffic, etc.) (Johnsen et al., 2009). To overcome this obstacle, normalization (relative) procedures are used (Samborski et al., 2009).

Despite considerable research predicting the N status in greens with remote sensors, no study using a remote device has answered the question of how much N must be applied when needed. The problem is apparently that there is not a defined goal in greens as there is for grain yield in agronomic crops. Carrow et al. (2010) pointed out that in turfgrass, yield is not the goal; rather, the goal is uniform density, color, and quality. These attributes respond to irrigation, fertilizer application, cultivation, climatic stresses, traffic stress, and pests; therefore, turfgrass performance may change with management practices and over seasons. In a golf green, there are several quality goals, mainly cover and color (both related), growth (related with cover), and green speed measures by ball roll. The question is how convert readings from remote sensors in kg N ha^{-1} in order apply in site- and time-specific management (precision turfgrass management) (Carrow et al., 2010). Similar procedures employed in agronomic crops may be applied in golf greens using relative measurements to develop an algorithm. In fact, Richardson et al. (2004) stated that in turfgrasses, we cannot yet make quantitative or even qualitative translations from reflectance data without first calibrating some sort of empirical model.

The purpose of this study was to develop N fertilization models (algorithms) with two remote sensors (digital camera and reflectance meter) for creeping bentgrass USGA greens, optimizing aesthetic and playability quality for the different seasons to improve N use efficiency under Mediterranean conditions.

2. Material and methods

2.1. Site and experimental design

The study was conducted at Rabanales Turfgrass Research Facility at the University of Córdoba, Córdoba, Spain (37° 54′ N, 4° 43′ W, 135 m above sea level) on 2-yr-old 'L-93' creeping bentgrass golf green over 2008, 2009, and 2010. The green was constructed according to USGA specifications (USGA Green Section Staff, 2004). The experimental design was a randomized complete block with treatments replicated three times. Treatments were N fertilizer rates 0, 3–5, 6–10, and 9–15 kg N ha^{-1} applied every 10 d. Within each N rate, the first value was applied in the summer and winter, and the second one was applied in the spring and fall. Plot size was 1.5 by 3.3 m. Weather-related parameters (30-yr average) for this Mediterranean area are as follows: average annual rainfall of 584 mm (39% October–December, 37% January–March, 19% April–June, and 5% July–September); average annual evapotranspiration of 1000 mm; average duration of dry period of 4–6 months; average annual temperature of 17.5 °C; average temperature in the coldest month of 9.5 °C; average temperature in the warmest month of 27.5 °C. The total rainfall–evapotranspiration during the study years was 660–1370, 744–1475, and 1165–1316 mm in 2008, 2009, and 2010, respectively. The number of days with daily maximum temperature above 35 and 30 °C (separated by dashes) were 61–102, 67–121, and 60–104 for each study year, respectively.

2.2. Green management

Nitrogen was applied as ammonium nitrate with a CO_2-pressurized backpack sprayer calibrated at 750 L ha^{-1}. The green was irrigated daily at 80% of the previous day's actual evapotranspiration. Actual evapotranspiration was estimated by adjusting the reference evapotranspiration with a crop coefficient of 0.85 as suggested by Allen et al. (1998) for turfgrasses. Reference evapotranspiration was computed by the Penman–Monteith equation. Irrigation was applied at 06:00 h to reduce the effect of wind. Irrigation run times were calculated by multiplying the treatment