DOES BLOCKING AFFECT EXPERIMENTAL EFFICIENCY ON SAND-BASED PUTTING GREENS?

Douglas E. Karcher,* Ryan M. Goss, Michael D. Richardson, Roch E. Gaussoin, and Margaret E. Secks

Abstract

Past experiments on sand-based putting greens have frequently used randomized complete blocked designs (RCBD), even though these experimental areas are relatively uniform with regard to external variables. Consequently, completely randomized designs (CRD) may have had better precision with which to estimate treatment effects compared with RCBD. The objective of this study was to estimate the relative efficiency (ERE) of a RCBD compared with a CRD when evaluating common parameters on sand-based putting greens. Uniformity trials were conducted in Arkansas and Nebraska on sand-based putting greens established with creeping bentgrass (*Agrostis palustris* Huds.). Estimated relative efficiency values were calculated for varying blocking schemes when measuring canopy temperature, soil temperature, soil moisture, clipping yield, and macronutrient content in plant tissues. Since canopy temperatures were time dependent, when those measurements were collected by a blocking scheme, the associated RCBD was approximately nine times more efficient than a CRD. For the remaining parameter and blocking scheme combinations, ERE values indicated that the precision between RCBD and CRD was similar. Therefore, it is likely that the precision with which treatment effects are estimated is not compromised from the use of RCBD on sand-based putting green trials.

When designing field experiments, blocking is often used to increase precision on treatment effects by reducing experimental error variance (Kuehl, 1994). Blocking stratifies experimental units into homogenous groups, and in field trials, plots are normally blocked according to their proximity to each other. Blocking will increase treatment precision only if plots are blocked according to one or more varying external factors (irrigation gradient, soil nutrient status, etc.). If an experimental area is homogenous, blocking may actually decrease the precision of estimating treatment effects. This results from a larger means square error (MS_E) term in the ANOVA since error degrees of freedom (df_E) are reduced without a comparable reduction in error sum of squares (SS_E). In this situation, a completely randomized design (CRD) would more precisely estimate treatment effects than a randomized complete block design (RCBD).

Sand-based putting greens constructed for field research usually contain a 30-cm rootzone with strict guidelines dictating the percentage of each sand particle size class permitted (USGA, 1993). In addition, greens are usually built with minimal slope and in full sun. Therefore, field trials on sand-based putting greens are typically conducted under uniform conditions with regard to sunlight exposure, topography, and soil physical and chemical properties. On these areas, a CRD may result in better precision when estimating treatment effects compared with a RCBD. However, since 1990, most published field studies conducted on sand-based putting greens have used a RCBD (Fig. 1). Of the 77% of the authors who reported their statistical design, 79% used a RCBD while 9% used a CRD. Furthermore, none of those who used a RCBD mentioned a varying external factor from which to create homogenous blocks of plots. In those cases, a CRD may have resulted in more precise estimates of treatment effects.

Uniformity trials consist of experiments where dummy treatments are applied and various parameters are measured to evaluate the inherent variation present within the experimental area (Hinkelmann and Kempthorne, 1994). Uniformity trial results can be used to compare the effectiveness of RCBD to CRD for a given experimental area. Uniformity trials conducted on sand-based putting greens should demonstrate if blocking is effective on these experimental areas. The objective of the following research was to compare the relative efficiency of a RCBD to a CRD when evaluating common turf parameters (canopy and soil temperatures, soil moisture, growth rate, and tissue nutrient concentration) on a sand-based putting green.

Materials and Methods

These studies were conducted at two locations on separate sand-based putting greens. The first site was the University of Arkansas Agricultural Research and Extension Center (Fayetteville, AR) and the second was the John Seaton Anderson Turfgrass and Ornamental Research Facility (Mead, NE). The putting greens at each site were built with minimal slope (<1%) and according to United States Golf Association recommendations (USGA, 1993). The Arkansas site was a 3-yr-old 'Crenshaw' creeping bentgrass green, whereas the Nebraska site was a 4-yr-old 'Providence' creeping bentgrass green. At each site, uniformity trials (no treatments applied) were conducted on experimental areas with 36 plots (each 0.9 by 1.8 m) arranged in a 6-by-6 plot fashion so that multiple blocking schemes (each block = 6 plots) were possible.

The following parameters were measured on each plot on 6 June 2001 in Arkansas and on 25 June 2001 in Nebraska: (i) canopy temperature with an infrared thermometer (Model 39650-04, Cole Parmer, Vernon Hills, IL) from three randomly selected subsamples, (ii) soil temperature at a 6 cm depth with a thermocouple thermometer (Model, 91100-50, Cole Parmer, Vernon Hills, IL) from three randomly selected subsamples, (iii) soil moisture to a 7.5 cm depth with a time domain reflec-

D.E. Karcher, M.D. Richardson, and M.E. Secks, Dep. of Horticulture, Univ. of Arkansas, 316 Plant Sciences Bldg., Fayetteville, AR 72701; R.E. Gaussoin and R.M. Goss, Dep. of Agronomy and Horticulture, 377 Plant Science, Lincoln, NE 68583-0724. A contribution of the University of Nebraska Agricultural Research Division, Lincoln, NE 68583. Journal Series No. 13934. Received 20 Nov. 2002. *Corresponding author (karcher@uark.edu).

Published in Crop Sci. 43:2295–2297 (2003).

677 S. Segoe Rd., Madison, WI 53711 USA

Abbreviations: CRD, completely randomized design; df_E, error degrees of freedom; ERE, estimated relative efficiency; MS_B, mean square for blocking effect; MS_E, error mean square; RCBD, randomized complete block design; SS_B, sum of squares for blocking effect; SS_E, error sum of squares.

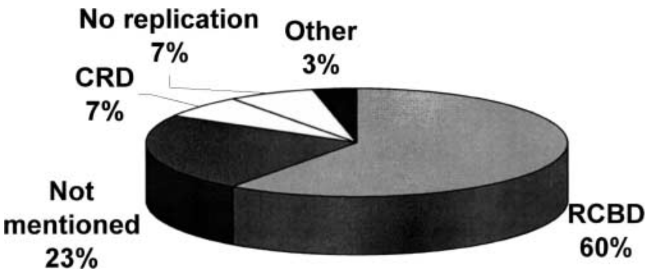

Fig. 1. A survey of peer-reviewed field research conducted on sand-based putting greens since 1990. A total of 30 papers were included in this study from Agronomy Journal, Crop Science, Fate and Management of Turfgrass Chemicals, HortScience, Horticulture Technology, and the International Turfgrass Research Journal.

tometry unit (Model Time FM, Mesa Systems Co., Medfield, MA) from three randomly selected subsamples, (iv) clipping yield by collecting clippings from a single pass through the center of each plot with a Toro 1000 mower (The Toro Co., Bloomington, MN), and (v) macronutrient content in plant tissue sampled from clippings harvested for yield evaluations and measured by the Agriculture Diagnostic Laboratory (University of Arkansas, Fayetteville, AR). Samples were analyzed by means of inductively coupled plasma (ICP) emission spectroscopy (Donahue and Aho, 1992) for all nutrients except N, which was analyzed by combustion analysis (Campbell, 1992). All parameters were measured beginning with the plot in the NW corner of the experimental area continuing eastward to the end of the plot row and then to the westernmost plot in the adjacent plot row to the south and continuing in the same fashion.

For each evaluation parameter, an analysis of variance was computed with block effects and experimental error as the only sources of variation (Table 1). The mean squares from each analysis were used to estimate the relative efficiency (ERE) of a RCBD compared with a CRD according to the following equation (Kuehl, 1994):

$$[(b - 1)\,\mathrm{MS(B)} + b(t - 1)\,\mathrm{MS(E)}]/[(bt - 1)\,\mathrm{MS(E)}$$

Although no treatments were applied in these uniformity trials, t equaled the number of units per block (6) in the computation of ERE. Separate ERE values were calculated for blocking schemes of both north to south and east to west.

An ERE value less than 1 indicates that a CRD is a more efficient design, while values nearly equal to 1 suggest that the two designs yield similar results. Values greater than 1 suggest that the RCBD is a more efficient design than CRD. Each ERE value represents the multiple of replications needed in a CRD to achieve the same level precision in estimating treatment effects as in the RCBD. For example, when blocking north to south at the Arkansas site, a CRD would need to contain 1.68 as many replications as the RCBD to achieve equal precision when estimating soil moisture, thus the RCBD is more efficient (Table 2).

Table 1. Sources of variation in uniformity trial ANOVA.

Source	df	MS
Blocks	$b - 1$	MS_B
Error	$b(t - 1)$	MS_E
Total	$bt - 1$	

Results and Discussion

All of the parameters measured resulted in ERE values near 1.0, with the exception of canopy temperature at both sites and soil temperature at the Arkansas site (Table 2). The majority of ERE values near or above 1.0 validate the use of RCBD in field trials on sand-based putting greens. For the parameters measured in these studies, there was enough variation among blocks to offset the loss in degrees of freedom when estimating experimental error. Consequently, precision was either affected very little or gained when using an RCBD compared with a CRD.

The large ERE values associated with canopy temperatures in the north to south blocking scheme were the result of ambient temperatures gradually increasing as the data was collected (canopy temperatures were taken over a 1 h period between 0900 h and 1100 h at both locations). Since measurements were taken from north to south, the northernmost block had a low mean temperature while the southernmost block had a high mean temperature. Therefore, effects among blocks were highly significant, resulting in large MS_B values, and subsequently, high ERE values. Although the ERE values indicate that nine times as many replications should be used if canopy temperature data were collected in a CRD, a CRD could have been much more efficient by using an analysis of covariance (ANCOVA) (Kuehl, 1994). An ANCOVA combines regression and ANOVA methodology to compare treatments on a common basis relative to the values of a covariate. Since measurement times affected canopy temperatures, experimental error could have been reduced by using measurement times as a covariate in an ANCOVA of canopy temperature. When time of measurement was used as a covariate in these studies, the ERE for canopy temperature in the north to south blocking scheme dropped from 8.38 and 9.50 to 1.34 and 2.13 at Arkansas and Nebraska, respectively.

These results indicate that enough variation existed

Table 2. Estimated relative efficiency of RCBD vs. CRD.

	Estimated relative efficiency†									
Uniformity trial	Canopy temperature	Soil temperature	Soil moisture	Clipping yield	N	P	K	Ca	Mg	S
Arkansas site										
North to south blocks	8.38‡	3.08	1.68	1.12	1.23	1.30	1.42	1.14	1.45	1.18
East to west blocks	0.88	0.89	0.96	1.34	1.03	1.06	0.93	0.95	0.95	0.95
Nebraska site										
North to south blocks	9.50	1.58	0.99	1.35	1.92	0.97	1.01	1.82	1.51	1.67
East to west blocks	0.87	0.87	1.00	1.05	0.95	1.51	1.34	0.97	0.91	1.02

† Estimated relative efficiency (ERE) = $[(b - 1)\,\mathrm{MS(E)} + b(t - 1)\,\mathrm{MS(E)}]/[(bt - 1)\,\mathrm{MS(E)}]$.
‡ ERE values in italics indicate where the precision to estimate treatment effects is gained significantly from using an RCBD instead of a CRD.

among blocks to justify the use of a RCBD. Therefore, future studies on sand-based putting greens can probably be blocked directionally (north to south or east to west), rather than by a known external variable, without a loss in experimental efficiency.

References

Campbell, C.R. 1992. Determination of total nitrogen in plant tissue by combustion, p. 21–24. *In* Plant analysis reference procedures for the Southern Region of the United States. South. Coop. Res. Bull. No. 368.

Donahue, S.J., and D.W. Aho. 1992. Determination of P, K, Ca, Mg, Mn, Fe, Al, B, Cu, and Zn in plant tissue by inductively coupled plasma (ICP) emission spectroscopy, p. 37–40 *In* Plant analysis reference procedures for the Southern Region of the United States. South. Coop. Res. Bull. No. 368.

Hinkelmann, K., and O. Kempthorne. 1994. Design and analysis of experiments. John Wiley and Sons, New York.

Kuehl, R.O. 1994. Statistical principles of research design and analysis. Duxbury Press, Belmont, CA.

USGA. 1993. USGA recommendations for putting green construction. USGA Green Section Record. 31(2):1–3.