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Practices Affecting Putting Green Speed

A Thesis in

Agronomy

by

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ABSTRACT

Putting green speed continues to receive attention because of the Stimpmeter. This instrument allows superintendents to quantitatively measure the speed of greens in a quick simple procedure: measuring the distance a golf ball rolls on the green after descending an inclined plane. The increase in attention has made it necessary to understand how management practices affect speed. Experiments designed to study some of these practices were conducted on creeping bentgrass, Agrostis palustris Huds., turf at the Joseph Valentine Turfgrass Research Center at The Pennsylvania State University. Factors studied were verticutting, brushing, mowing height, wetting agent, water management, rolling, topdressing, and creeping bentgrass varieties. Also, experiments were conducted to determine if golf ball deceleration varies on different surfaces and how firmness affects putting green speed. Weekly light verticutting increased speed 0.5 to 1.1 ft on plots mowed at 6/32 inch in 1983 and 1984. An increase of 0.5 to 1.2 ft on plots mowed at 4/32 inch occurred in 1984 but not 1983. Verticutting brushing had a similar effect to verticutting alone, while brushing had little effect on speed. Mowing height was shown to have the greatest impact on speed. An increase of 2 feet occurred when mowing height was lowered from 6/32 to 4/32 inch. However, only a 0.3 ft increase occurred from 4/32 to 3/32 inch. Percent turf cover decreased as the mowing height was lowered. Wetting agent applied to turf at a standard rate did not change the speed. Plots mowed at 4/32 inch and irrigated daily with 0.3 inch of water were not slower than nonwatered plots on 7 of 10 days. There was only a 0.5 ft decrease on the other three days. Average speed over 10 days was not affected by either treatment. Single and double rolling with a modified Jacobsen mower increased speed an average of 0.8 and 1.3 ft, respectively. The increase was immediate but nonaccumulative and did not last for more than 24 hours. There was no significant difference between 22 seeded varieties. The difference between the means was 0.6 ft. Sand topdressing did not change speed after 28 light frequent applications or five heavy applications on thatched creeping bentgrass turf. To more effectively firm the surface, groove verticutting and aerifying followed by sand topdressing was done in September 1983, and April and May 1984. Speeds during the summer of 1984 still had not been increased due to sand topdressing. A 10-foot Stimpmeter, opposed to the standard 3-foot model, was used to determine golf ball deceleration rates. At 4/32 and 6/32 inch mowing heights, deceleration rates were 1.61 and 2.24 ft/sec^2, respectively. Instron compression measurements confirmed that the sand topdressing had not firmed the surface. There was no deformity difference between the topdressing and check treatments. The Instron did measure differences between mowing heights. Heights of 3/32 and 4/32 inch deformed less than 6/32 inch indicating the lower heights had firmer surfaces. This firmness contributes to faster speeds.

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INTRODUCTION

Putting green speed continues to receive attention on golf courses. The Stimpmeter has made it possible to quantify speed accurately and easily. It was developed by Edward Stimpson in 1937 (Stimpson, 1937). In 1978 the United States Golf Association (U.S.G.A.) began selling a modified Stimpmeter to member clubs. Golf balls are rolled down this device, an inclined plane, and across the putting green. Six balls are rolled, three each in opposite directions. The average distance the ball rolls is calculated and this indicates the speed of the green with longer distances given the relative term "fast." Professionals request fast greens for tournaments. Television coverage of professional tournaments with announcements of Stimpmeter measurements has encouraged the average golfer to request faster greens for regular play. Since superintendents are responsible for managing greens they must know how to adjust practices to regulate the speed.

Management practices known to yield faster greens include lower heights of cut, lower nitrogen fertility and multiple mowings (Throssell, 1981). However, these conditions may stress the turf of poor quality greens and encourage invasion from moss, algae and weeds.

Low surface moisture is commonly believed to cause an increase in speed, and conversely, rain or irrigation is believed to decrease speed. However, if moisture from irrigation or rain infiltrates or evaporates, the speed may not change. Throssell (1981) found that speed decreased slightly from moisture on areas mowed at 2/32 and 3/32 inch bench settings, but increased at 6/32 inch. He indicated further research was necessary.

Rolling is an old practice used at such clubs as Oakmont Country Club and Merion Golf Club in Pennsylvania to firm greens. More recently rolling and multiple mowings have been used as regular management practices to provide a uniformly fast speed for the Masters Tournament at the Augusta National Golf Club. At Augusta, major emphasis is placed on putting large undulating bentgrass greens. Because of large fairways and little rough, professionals are usually playing from good lies enabling them to better control the ball. More players hit greens in regulation so the tournament is decided by approach shot placement on the greens and the fewest putts. Therefore, the officials at Augusta and other tournaments want uniform fast greens, with Stimpmeter readings beyond 10 feet.

Many golf operations either do not have the means or desire to produce fast greens by lowering the mowing height. Some must mow at 3/16 inch or higher to reduce turf stress, especially when annual golf rounds exceed 30,000. Speed of play is better maintained with slower greens. At 3/16 inch mowing height speeds of 7 to 8 feet have been reported (Throssell, 1981) and grain can be a severe problem. Grain is defined as the tendency for turfgrass leaves and stems to grow more horizontally in one or more directions rather than vertically (Beard, 1973). At higher mowing heights shoot density is lower. This allows plants to escape mowing because they have space to grow horizontally. Grain reduces putting quality by disrupting trueness of roll. Superintendents can eliminate grain by brushing or verticutting. They can also establish varieties with a more vertical growth habit on newly constructed greens. Vertically oriented putting turf is considered to be high quality. These practices should allow superintendents to produce both good putting and turf quality.

To better understand putting green speed, the forces acting on the rolling ball must be identified. Friction is obviously believed to be the main force affecting deceleration; less friction means faster speeds. Since rolling friction is less the more rigid the surface (Weber et al., 1952), firming the surface should increase speed. Therefore, if topdressing firms the surface it should increase speed. Unfortunately, there was no apparatus for measuring turf firmness in the field. Methods for determining such variables need to be developed and tested.

This research was undertaken to determine and document the effect of certain management practices on speed beyond those studied by Throssell. Also, efforts were made to better understand why management practices alter speed. The results of this research will hopefully help golf course superintendents meet the speed demands of their membership and reduce the risk of severe turf stress.

The objectives of this research were:

1. To study the effect mowing height, verticutting, brushing, wetting agent, water management, rolling, and topdressing have on putting green speed;
2. To determine if deceleration is uniform on different surfaces; and
3. To determine if the firmness of a turf canopy affects speed.

LITERATURE REVIEW

In 1978 the United States Golf Association released the Stimpmeter for measuring the speed of putting greens. It is an improved version of an inclined plane developed by Edward Stimpson (Stimpson, 1937). The Stimpmeter is a straight aluminum bar 36 inches long, 1.75 inches wide and 0.75 inches thick. A 145° v-shaped trough on the top serves as a track in which a golf ball rolls. A tapered bottom end rests on the putting surface. A notch, located six inches from the top, holds a golf ball and ensures repeated release from the same height at a 20° angle. The notched end is raised until the ball rolls out and then is held motionless until the ball rolls onto the green. Six balls are rolled, three each in opposite directions and the average distance is termed "speed." Differences in opposite direction a ball rolls should not exceed 20%.

Before the commercial release of the Stimpmeter, U.S.G.A. agronomists tested over 1,500 greens and developed a speed table (Table 1).

Table 1. Guidelines for putting green speed established by the United States Golf Association (1979).

Regular Play		Tournament Play
8'6"	Fast	10'6"
7'6"	Medium-Fast	9'6"
6'6"	Medium	8'6"
5'6"	Medium-Slow	7'6"
4'6"	Slow	6'6"

A conflict appears in the literature concerning the table. The Stimpmeter Instruction Booklet states that this table is for general information only and not an attempt to standardize speeds (U.S.G.A., 1979). However, former National Director of the U.S.G.A. Green Section, A. M. Radko, stated "with the Stimpmeter the superintendent can obtain a numerical reading which can be compared with the speed table and used as a guide for adjusting management practices to obtain the speed his membership wants" (Radko, 1978). Possibly more people have read the last statement because the guidelines have become a standard. Many memberships request speeds greater than 9 ft; in essence they want tournament speeds daily.

U.S.G.A. agronomists have devoted five articles in their Green Section Record regarding the Stimpmeter (Bengeyfield, 1982; Hoos, 1982; O'Brien, 1981; Radko, 1984; Zontek, 1983). Two main points are stressed. First, the Stimpmeter allows superintendents to determine management practices effects on putting green speed and, second, it aids superintendents in preparing uniform putting green speeds on the golf course. The articles do not suggest all golf courses should have fast greens. The speed of a set of greens must be at a level suited for the membership and the conditions that prevail.

Previous to the Stimpmeter researchers used an Arnott putter, a device with a loaded pendulum head mounted on an adjustable tripod, to determine which grass was best suited for putting greens (Monteith, 1929). Later the same device tested velvet, colonial and creeping bentgrasses, established from either stolons or seeds, for drift on a 6% slope surface (Grau, 1933). Dudeck and Peacock (1981) worked with drift on ryegrass overseeded bermuda greens. They used an angle iron as an inclined plane and measured the distance a ball rolled on the green and the angle of drift from a straight line. They found that there were varietal differences in the distance the ball rolled but no difference in the angle of drift.

Though invented in 1937, the Stimpmeter received little use until 1976 when the U.S.G.A. made its modified version. Stimpmeter measurements have indicated differences in green speeds between and within golf courses in the northeast. Engel et al. (1980) found a range of 6.25 to 9.25 ft. Differences among greens on the same course were from 0.5 to 2.0 ft, with the greatest variation occurring on non-tournament courses. Radko (1981) reported similar findings on greens across the country. Greens ranged from 5 to 9 ft between courses, and up to 2.5 ft on the same course.

Throssell (1981) supported their work with a survey of 24 Pennsylvania golf courses. He found a range in speed from 5 to 10 ft and variation within a course of 0.3 to 2.0 ft. His study represents the best documentation of management factors versus Stimpmeter results. Factors studied were different heights of cut, multiple mowings, limited moisture, mowing direction, nitrogen levels, change in speed throughout the day, aerifying and topdressing, verticutting, variety differences and mowing frequency.

Throssell showed mowing height had the single largest impact on speed. As the height of cut decreased speed increased. Multiple mowings increased speed with the greatest increase coming from the first mowing. Moisture from either rain or irrigation was shown to decrease speed at 2/32 and 3/32 inch, but increased speed at 6/32 inch. Mowing direction increased speed with the direction of mowing and decreased speed against the direction of mowing. This supported Engel's (1980) findings in an earlier study. Nitrogen levels also proved to have a major impact on speed. As N increased from 1 to 6 lb/1000 ft^2 per growing season, speeds decreased. There was no significant difference in speed measured between 0700 and 1900 hours. These findings documented statements made by Thomas (1978). Aerification decreased speed compared to a non-aerified check while topdressing decreased speed 0.4 to 0.8 ft in the first 8 days after which speed increased 0.5 to 1.2 ft. Variety speeds had a maximum of 0.75 ft difference.

Throssell (1981) stated that seasonal variation and sometimes daily variation in speed is often greater than variation due to management practices.

EXPERIMENTAL SITES

The research was conducted at the Joseph Valentine Turfgrass Research Center at The Pennsylvania State University in University Park, Pennsylvania. Approximately 38,000 ft^2 of creeping bentgrass turf greens was used for 10 experiments.

Area I

A Hagerstown silt loam that had been surface modified through the addition of sandy loam topdressings was the site of a sand topdressing study conducted in 1983 and 1984. The turf stand was 8-yr-old Penncross and Penneagle creeping bentgrasses, each seeded on three replicated 6 by 72 ft plots in a randomized block design. The site was managed as a putting green type turf with automatic irrigation, moderate fertilization (refer to Appendix, Table 11 for rates and dates of N), disease control, and an average of six mowings a week at 5/32 inch with a Toro Greensmaster Triplex. The site was free of *Poa annua* L. infestation.

Area II

This area was used to study verticutting and brushing, varietal mowing height, wetting agent, moisture, mechanical rolling, varietal evaluation, and deceleration. The green had a modified soil with a 7:3:1 volume ratio of sand, soil and peat and it was seeded in August of 1977. Four areas totalling 32,000 ft^2 were used: (1) Varieties with height of cut varied using two of three varieties, Penncross and Penneagle, 6 by 72 ft plots, with three replications in a randomized block design, (2) Penncross block, 8500 ft^2, (3) Penneagle block, 8500 ft^2, and (4) Varietal creeping bentgrass block using 22 seeded entries, 6 by 24 ft plots, with three replications in a randomized block design.

For two years following establishment, the site was managed into a mature putting green type turf with automatic irrigation, moderate fertilization, disease control, except for varietal evaluations, and an average of five mowings a week at 5/32 inch with a Jacobsen Greens King Triplex.

Measuring Procedure

The measuring procedure outlined in the U.S.G.A. Stimpmeter Booklet (1979) was used in all experiments except deceleration. Speed was determined by the average roll of three balls in each of two opposite directions. Measurements within each plot where taken from the same spots marked by 1/2 inch diameter holes filled with white sand. All measurements were taken weekly, between 1000 and 1400 h at 45 or 90 degrees of the last mowing direction, and when possible following two or more consecutive days of mowing. The author took all measurements except varietal evaluation, where another person assisted. Speeds were measured to the nearest tenth of a foot with an 11-foot measuring stick (Figure 1). It was devised to increase time efficiency compared to a measuring tape.

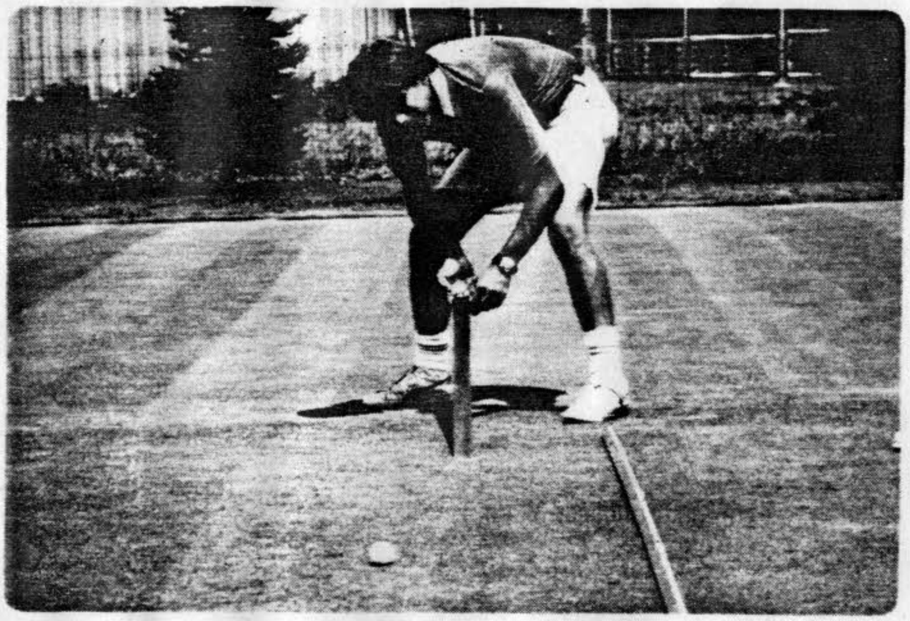

Figure 1. Measuring putting green speed with Stimpmeter, golf ball, and 11-foot measuring stick.

VERTICUT AND BRUSHING EXPERIMENT

Materials and Methods

Some golf operations mow at 6/32 inch or higher to reduce turf stress. Speeds on 6/32 inch have been reported to range from 5 to 7.5 ft (Throssell, 1981). Some players consider this too slow. Therefore, verticutting and brushing were applied as treatments at 6/32 and 4/32 inch heights of cut to determine if they increased speed. Major interest was placed on the higher height.

An 8,500 ft^2 block of 5-yr-old Penncross creeping bentgrass was divided into six blocks, three each mowed at 6/32 and 4/32 inch, respectively. The area received six daily mowings per week with walking mowers. The site was topdressed in the fall of 1982 with a PGS Number 1[1] sand at 400 lbs/1000 ft^2. In the fall of 1983 it was aerified and topdressed with the same type sand. For the 1983 and 1984 seasons it received regular maintenance watering, preventive fungicides and 2.5 lb N/1000 ft^2 per season. Refer to Appendix, Table 11, for dates of N application.

Beginning 17 June 1983, each triple replicated height of cut block was divided into four treatments: 1) weekly double brushing, 2) weekly double light verticutting, 3) weekly double brushing X double light verticutting, and 4) a check.

A Bunton walking mower with a rotary brush set 1/8 inch below the rollers was used for brushing. Each treatment consisted of two passes

[1]PGS Number 1 sand is a product of the Pennsylvania Glass Sand Corporation, Mount Union, PA.

back and forth on the same line. On brushing days the check treatments were double mowed with the Bunton without the brush. Four brushing directions, 1) north to south, 2) east to west, 3) northeast to southwest, and 4) northwest to southeast were alternated, with each direction occurring monthly.

A Hahn Triplex was used for the double light verticut treatment. The reels were set 1/8 inch above the roller bottoms and run at 3,700 rpm at perpendicular directions. The same directions were used throughout the experiment by necessity of plot size.

From 17 June to 6 September 1983, eight treatments were made on a weekly schedule, and 20 in 1984 from 7 May to 2 October. Weekly speed measurements totalling 12 and 21 in 1983 and 1984, respectively, were taken two or three days after treatments.

Three inches of rain the first week of August 1984 contributed to conditions leading to an algae infestation and differences were observed between treatments. Visual ratings were taken on 12 August and 6 November 1984, using a scale of 1 to 9 with 1 = none.

Analyses of variance were calculated for speed and algae data using a 2 x 2 x 2 factorial in a randomized block design. Duncan's multiple range test was used to separate treatment means.

Results and Discussion

The results will be discussed for the treatments by heights of cut beginning with the 6/32 inch. After the first treatment, verticut and verticut X brushing were significantly faster (0.5 and 0.9 ft, respectively) than the check (Figure 2). Brushing alone was not significantly different than the check. After three weeks the increase from verticutting was 1.0 ft. Treatments were not applied the week of

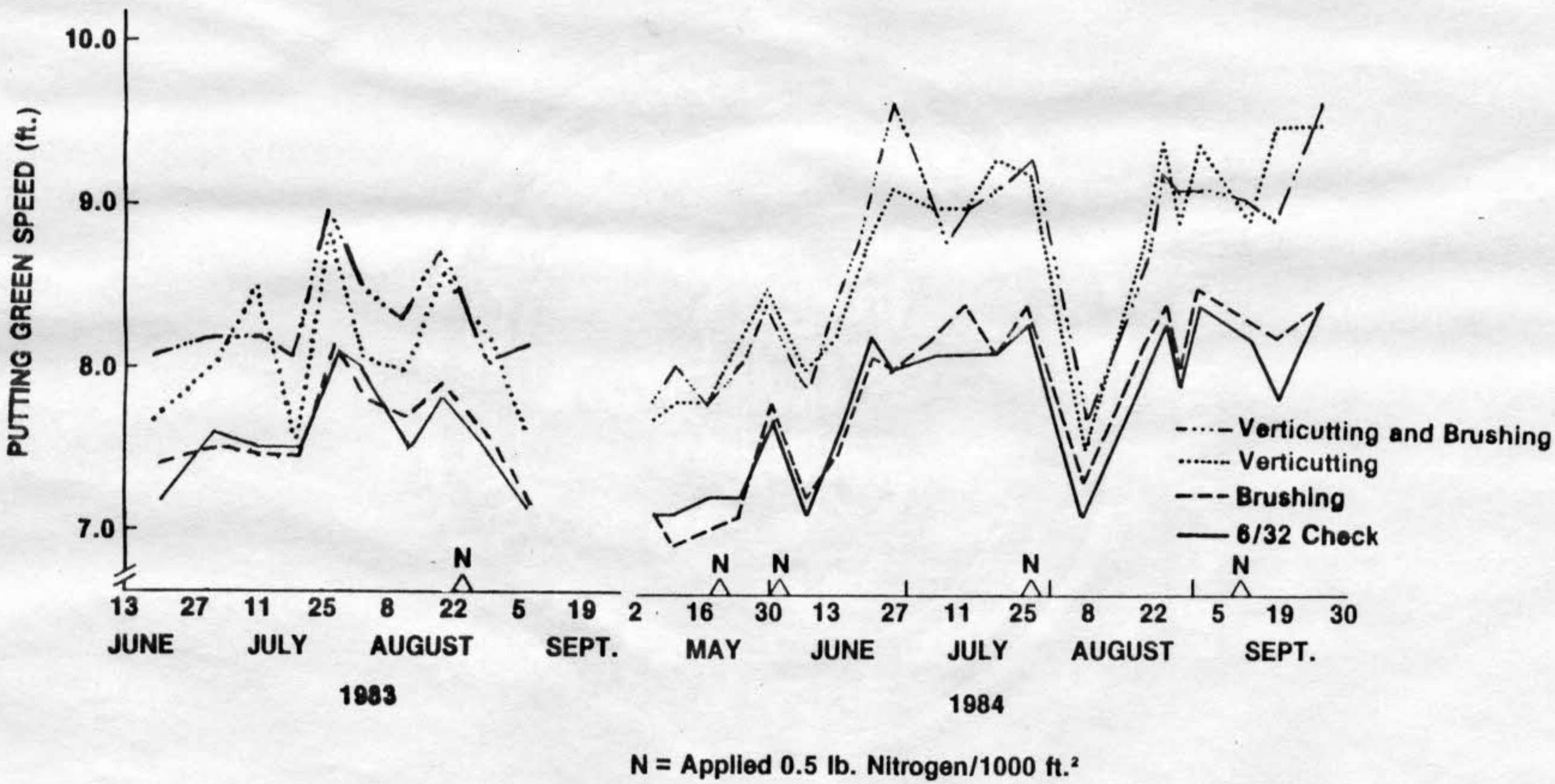

Figure 2. Putting green speed for 1983 and 1984 of verticutting, brushing, verticutting and brushing, and check plots of Penncross creeping bentgrass mowed at 6/32 inch.

14 July. A speed depression of 0.8 ft on verticut plots reflects the skip. The previous treatment was 8 July indicating a verticutting residual of less than 10 days. The verticutting X brushing remained 0.75 ft faster than the check, but there was no significant brush by verticut interaction. The significant speed increase from verticutting returned upon resumption of the treatment schedule. Speeds on 2 and 9 August supply further evidence for short residual of verticutting because readings were taken six days after treatment application. On these dates verticutting was not significantly faster than the check. Verticutting was significantly faster than the check the last three dates.

In 1984, the data were more consistent. Again verticutting and verticutting X brushing were significantly faster than brushing and the check. There was no significant brush by verticut interaction. Therefore, the speed increase from the combined treatment was due to verticutting. The increases from verticutting ranged from 0.5 to 1.1 ft. On 6 and 20 August, no significant difference occurred between the treatments. Both readings were taken 6 days after treatment application. Three inches of rain from 2-5 August delayed speed measurement until 6 August. The greens had not been mowed the previous day and rapid growth due to rain and an application of 0.5 lbs/1000 ft^2 of soluble N on 28 July, contributed to the decrease in speeds on all treatments. The 20 August measurement showed the check treatment had completely recovered from the speed decrease. After a 21 August treatment the speeds on verticut plots returned to previous July levels.

At the 4/32 inch height of cut the differences due to treatments were not as dramatic, especially in 1983. All four treatments were similar with only 0.5 ft separating them (Figure 3). The verticut treatment removed less leaf tissue on this mowing height because the plants were 2/32 inch shorter. No significant treatment difference occurred in 1983. However, treatment responses occurred in 1984. The seasonal variation could not be explained by weather data. Verticutting and verticutting X brushing were significantly faster than brushing alone and the check. The increases from verticutting ranged from 0.5 to 1.1 ft. There was a decrease in speed in late June to early July that did not appear on the 6/32 inch height of cut and it cannot be explained by either N application, mowing, rain or skipped treatments.

Both years N applications were shown to cause speed reductions during actively growing periods. In August 1983, and June, July, and September of 1984 all treatments decreased approximately 0.5 ft. The lack of N effect in May 1984 is believed to be due to the cold temperatures slowing growth.

The AOV showed significant speed differences between height of cut for all dates at the 0.01 level. The coefficient of variation ranged from 1.2 to 4.9%. Speeds for 6/32 and 4/32 inch ranged from 7.0 to 9.5 and 8.8 to 12.0 ft, respectively.

Algae ratings showed significant differences between mowing heights, treatments and mowing height by treatment interaction at the 0.05 level. The values reported in Table 2 are means of three replications for each date.

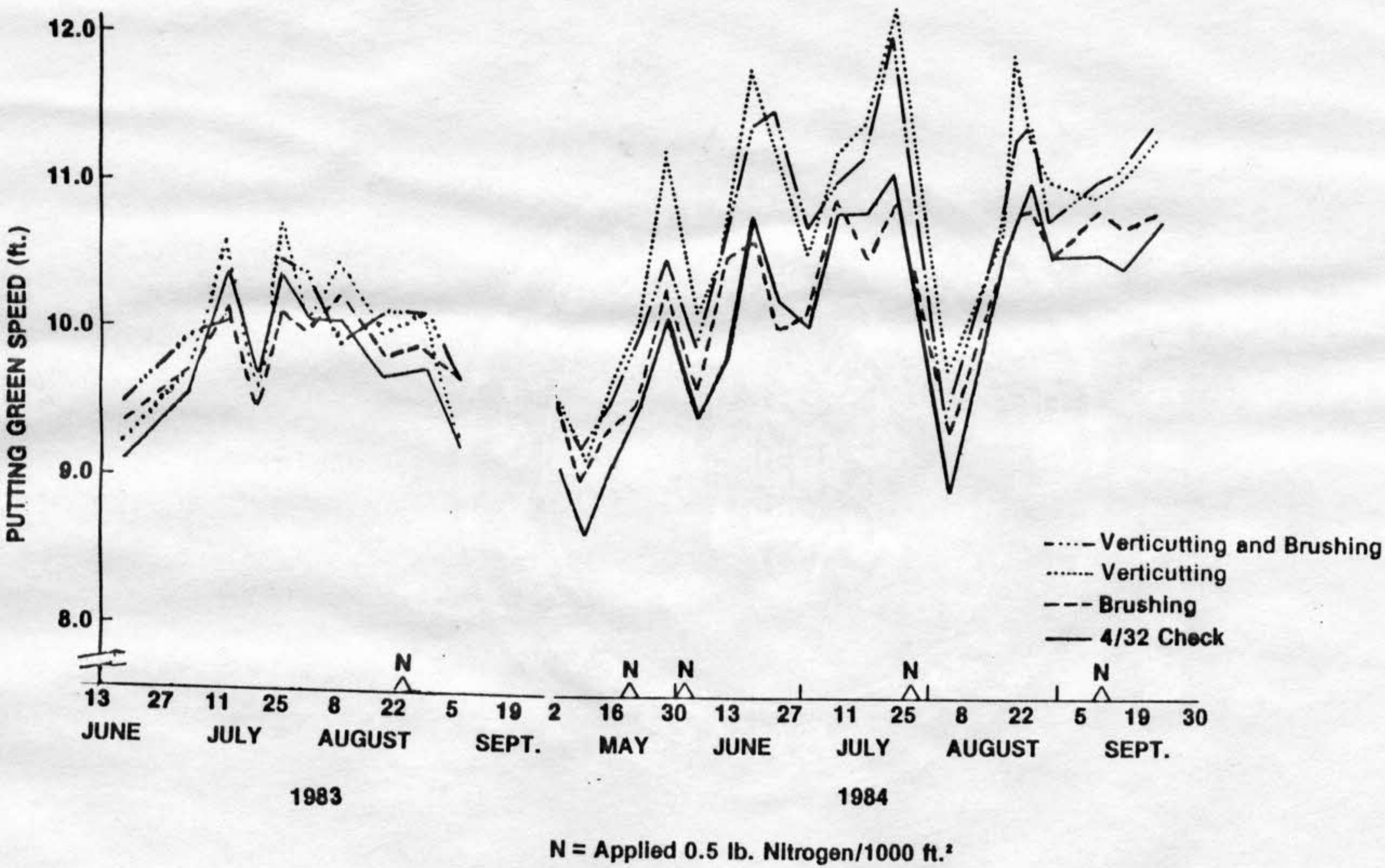

Figure 3. Putting green speeds for 1983 and 1984 of verticutting, brushing, verticutting and brushing, and check plots of Penncross creeping bentgrass mowed at 4/32 inch.

Table 2. Algae ratings on verticut and brush treatments at 4/32 and 6/32 inch.

Treatment	Height of Cut			
	4/32 inch		6/32 inch	
	12 AUG	6 NOV	12 AUG	6 NOV
Verticut	4.0 a†	4.3 a	2.2 cd	2.8 bc
Brush	3.8 a	4.3 a	1.7 de	2.3 cd
Verticut and Brush	3.8 a	4.3 a	2.7 bc	3.3 ab
Check	3.8 a	4.0 a	1.2 e	1.5 e

Scale 1-9, 1 = none

†Means followed by the same letter are not significantly different at the 0.05 level.

The greatest incidence of algae occurred at low mowing heights. At 4/32 inch the algae population was approximately 30% on all treatments. At 6/32 inch none of the treatments had as high an algae population as 4/32 inch but there were greater treatment differences. The verticut and brush treatment had the largest amount of algae and the check the lowest.

Thinned turf seemed most susceptible to algae infestation. Thinning was caused from stress of low mowing heights or by mechanical thinning from vertical mowing. With limited competition, increased light, and high surface moisture conditions, algae appeared.

VARIETAL HEIGHT OF CUT

Materials and Methods

Uniform putting green speeds throughout the season are desirable. In 1983 and 1984, speeds were taken on two varieties at three heights of cut to monitor seasonal changes. Three 24 by 54 ft blocks were mowed at 3/32, 4/32, and 6/32 inch, respectively. Each block contained three replications of Penncross, Penneagle, and Seaside creeping bentgrass in 6 by 24 ft plots. The Seaside was not used in this study. They were mowed six times a week with walking mowers following dew removal. The area received regular maintenance watering, preventive fungicides, and approximately 2.5 lbs N/1000 ft^2 per season. Refer to Appendix, Table 11 for dates of N application.

Weekly speed measurements were taken on two varieties mowed at 3/32, 4/32, and 6/32 inch heights of cut from 7 June to 20 October 1983, and from 2 May to 3 October 1984 on the 3/32 and 6/32 inch areas. Speed readings were taken after mowing, on a 45 degree angle to the direction of the current days mowing, and at approximately the same time each day.

On 9 May 1984, a cover rating was taken on this area. It had been observed that the treatment mowed at 4/32 inch and previously at 2/32 inch for three years was thin and unable to fill in if maintained at 4/32 inch. Therefore, the decision was made to raise the height from 4/32 to 6/32 inch. The rating was made prior to raising the height. A scale of 1 to 10 was used with 1 = bare soil and 10 = 100% cover.

A split block experimental design, with height variables stripped across varieties was used in this test. Analyses of variance were calculated for speed and cover ratings on individual dates and combined dates. Duncan's multiple range test was used to compare means.

Results and Discussion

Speeds were typically slower in the spring at all heights and increased during the season (Figures 4 and 5). Throssell (1981) showed the same trend during 1980. It was believed low temperatures contributed to slow spring speeds. May 1984 was cold accumulating 54 growing degree days. The base to obtain growing degree days was 60°F because that is the minimum temperature of optimum shoot growth for cool season grasses (Beard, 1973). During this time an audible "chatter" occurred as the ball rolled across the surface. The nature of the plant material created an uneven surface. Regular mowing produced few clippings indicating bentgrass growth had not begun. In June the temperature increased, 248 growing degree days, stimulating growth. The speed increased and the chatter disappeared.

In 1983, seasonal variations of 3.2 and 2.5 ft were recorded on the 4/32 and 3/32 inch areas, respectively. This large variation was greater than seasonal variation of less than 2 ft reported by Throssell (1981) and Radko et al. (1981).

There was no daily or seasonal statistical difference between varieties. Over the two seasons the mean speeds on Penncross and Penneagle were 8.9 and 8.8 ft, respectively.

Most of the seasonal variation can be explained by management. An application of 0.5 lbs N/1000 ft^2 caused the speed reductions on all heights on 6 September 1983 and 8 June 1984. Throssell (1981) showed similar decreases from nitrogen application. Speed reductions on 18 July 1983 and 6 July 1984 occurred because measurements were taken the day after a non-mowing day. The decrease was greater for the lower mowing heights. A 0.5 lb N application and a disruption in the mowing

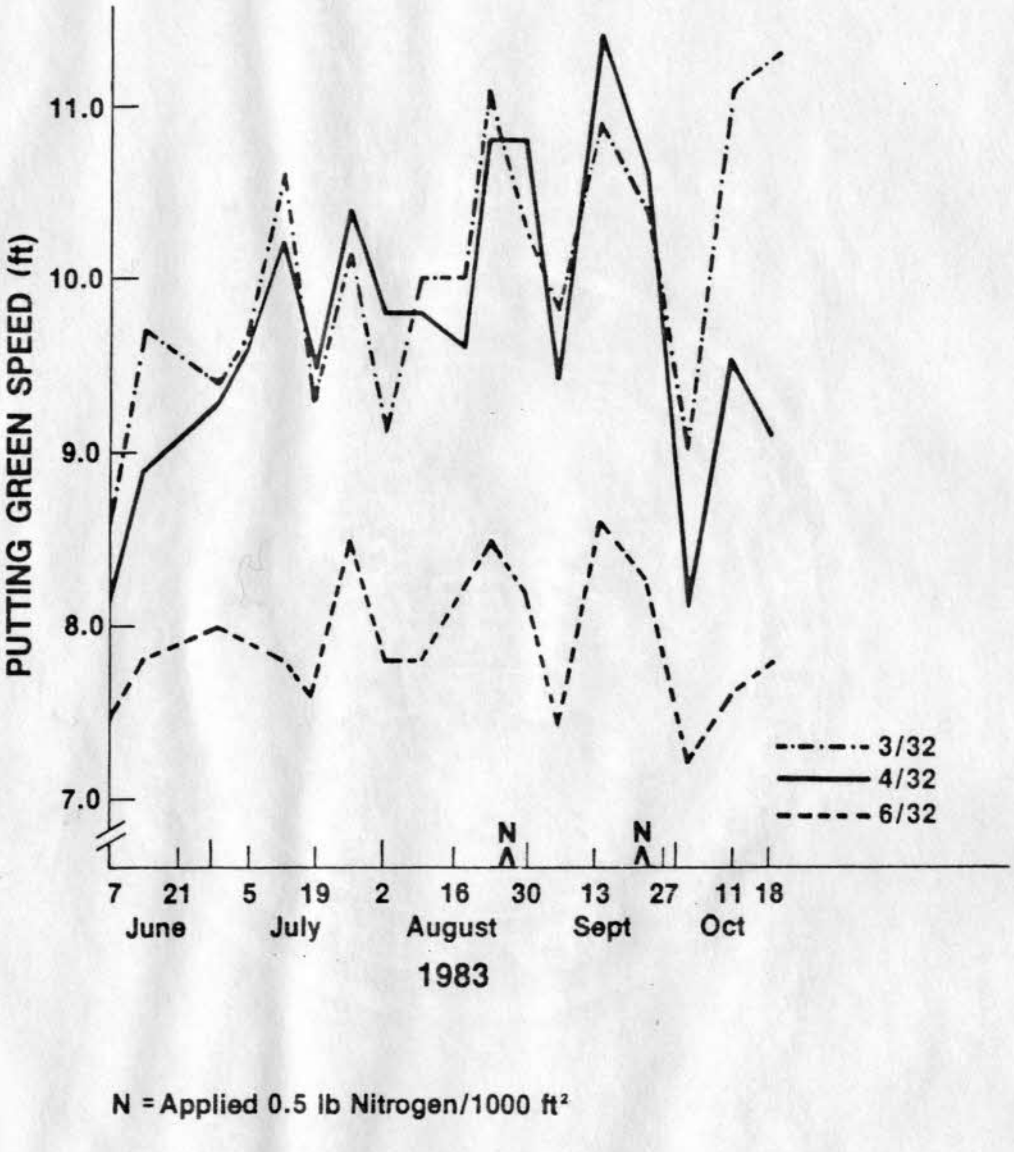

Figure 4. Putting green speeds during 1983 comparing 3/32, 4/32, and 6/32 inch mowing heights.

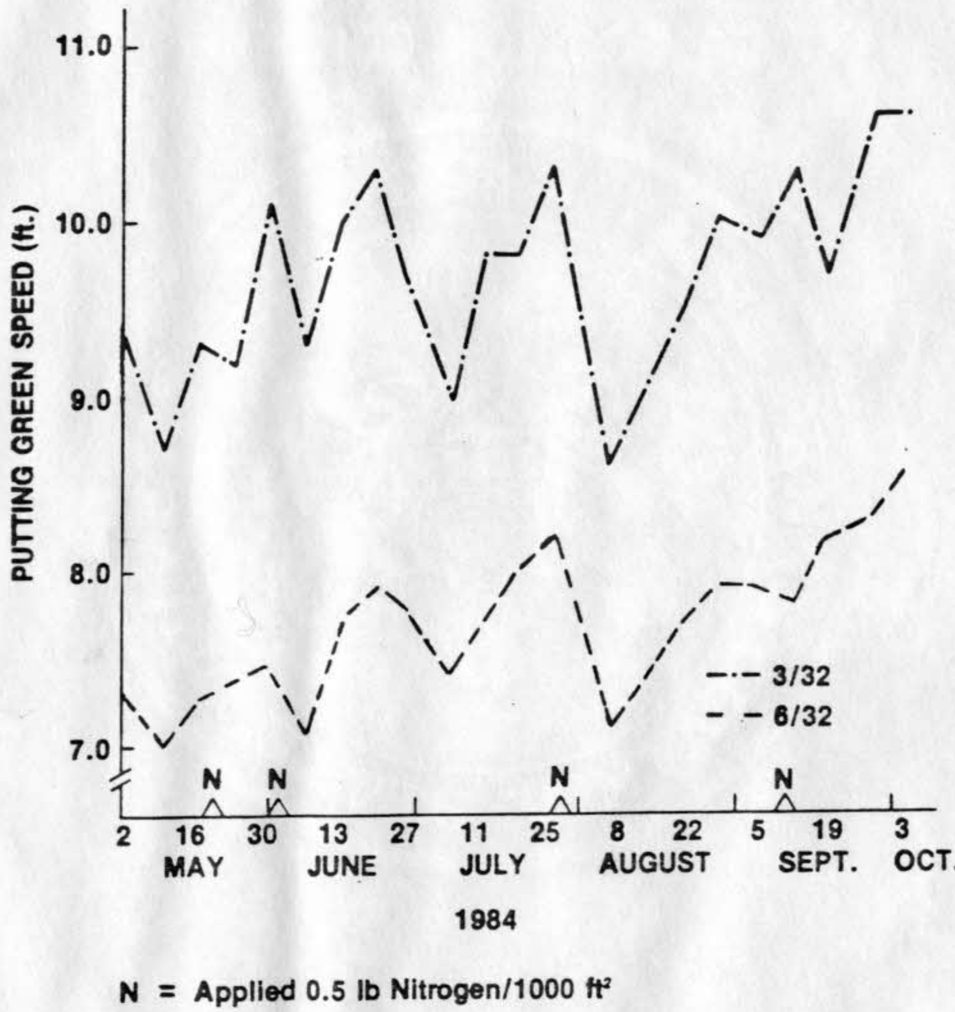

Figure 5. Mean putting green speeds during 1984 comparing 3/32 and 6/32 inch mowing heights.

schedule caused the large decreases on 3 October 1983 and 6 August 1984. Speed decreases greater than 1.5 ft occurred on these dates. The depression on 2 August 1983 cannot be explained from weather data, fertilizer, or mowing. In summary, the decreases in speed occurred because of increases in grass length from either a skipped mowing or growth stimulation from nitrogen.

The AOV for each date showed a highly significant difference between heights of cut at the 0.01 level. The CV's ranged from 0.9 to 6.2%.

A significant difference between 3/32 and 4/32 inch heights occurred on only 8 of 18 dates during 1983 while 4/32 was always significantly faster than 6/32 inch. Speeds for 3/32 and 6/32 inch mowing heights were similar for both seasons. The average speeds for 3/32, 4/32, and 6/32 inch heights of cut were 10.0, 9.7, and 7.8 ft, respectively. An average increase of 0.3 ft does not justify mowing at 3/32 inch.

The average speeds for 3/32 and 6/32 inch were the same as those reported by Throssell (1981). Since those areas were mowed at the same height for five seasons, future average speeds would probably not change.

The cover rating showed a significant difference between mowing heights at the 0.05 level but no significant difference between varieties or height by variety interaction (Table 3). The 6/32 inch height had 100% cover on both varieties. The low heights of cut severely thinned the turf.

Table 3. Turf cover ratings taken on three heights of cut on two varieties.

Variety	Height of Cut		
	6/32 inch	3/32 inch	4/32 inch
Penncross	10.0 a†	8.6 b	7.2 c
Penneagle	10.0 a	8.2 b	7.3 c

Scale 1-10, 1 = bare soil

†Means followed by the same letter are not significantly different at the 0.05 level.

WETTING AGENT, WATERING, AND ROLLING

Materials and Methods

In 1983 an 8,500 ft^2 block of Penneagle creeping bentgrass was mowed with a Toro Series 4 walking mower at 4/32 inch six times a week. This area was used for wetting agent, water vs. no water, and rolling experiments. Preventive fungicides and 2.5 pounds N/1000 ft^2 per growing season were applied. Refer to Appendix, Table 11, for dates of N application.

Wetting Agent

Wetting agents are used on putting greens to increase the effective wetting of the soil. They give the turf an oily, limp appearance and the impression of faster green speeds. Therefore, an experiment was designed to determine if a standard rate of wetting agent increased green speed and if it did, how long the increase lasted.

On 12 July 1983, 6 oz/1000 ft^2 of Surf Side 37[2] wetting agent in one gallon of water was sprayed on one-half of eight 9 by 28 ft plots. It was immediately watered in with a rose cone nozzle. Speeds were compared to check plots for five days following treatment. An analysis of variance was calculated using a randomized complete block design.

Water vs. No Water

To determine if water decreases speed, a water versus no water experiment was conducted in conjunction with the wetting agent experiment.

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[2]Surf Side 37 is manufactured by Montco Product Corporation, Ambler, Pennsylvania.

From 12 July to 22 July 1983, two treatments, water and no water, were divided among the eight 9 x 28 ft plots, with four replications in a completely random design. The water treatment consisted of 0.3 inch of water applied daily at noon with a rose cone nozzle (Figure 6). It did not rain during the experiment and maximum temperatures ranged from 86° to 90°F. The nonwater treatment was syringed daily starting 13 July at 1400 h. Speed measurements were taken daily at 1100 and 1300 h prior to and following water treatment.

An analysis of variance was calculated and Duncan's multiple range test was used to compare treatment means.

Rolling

To determine the effects of rolling on speed, a Jacobsen hand mower with a mounted 25 lb frame and a 45 lb sandbox were used in August 1983 (Figures 7 and 8). It was designed at the Augusta National Golf Club. Two separate experiments were performed, single and double rolling. In each experiment treatments consisted of two, four, or six consecutive days of rolling plus a check with eight replications. The individual plot sizes were 9 by 14 ft. The experiments were run on the same plots but single rolling was conducted two weeks before double rolling. Speed measurements were made in a direction perpendicular to rolling and within one hour of rolling of all treated plots.

An analysis of variance was calculated using a randomized block design. Duncan's multiple range test was used to compare treatment means.

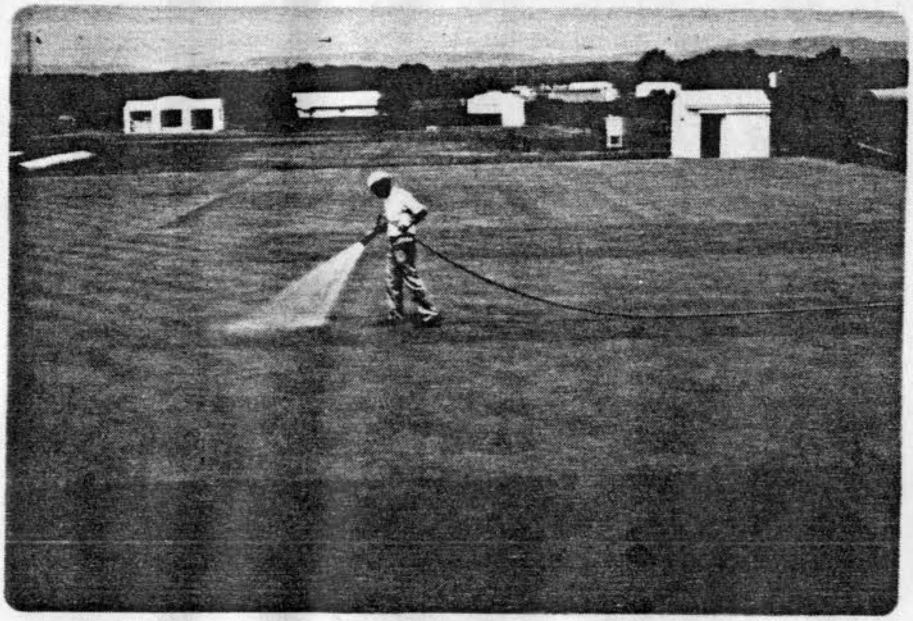

Figure 6. Applying 0.3 inch water treatment with a rose cone nozzle. The light colored plots indicate the moisture stress on the nonwater treatment.

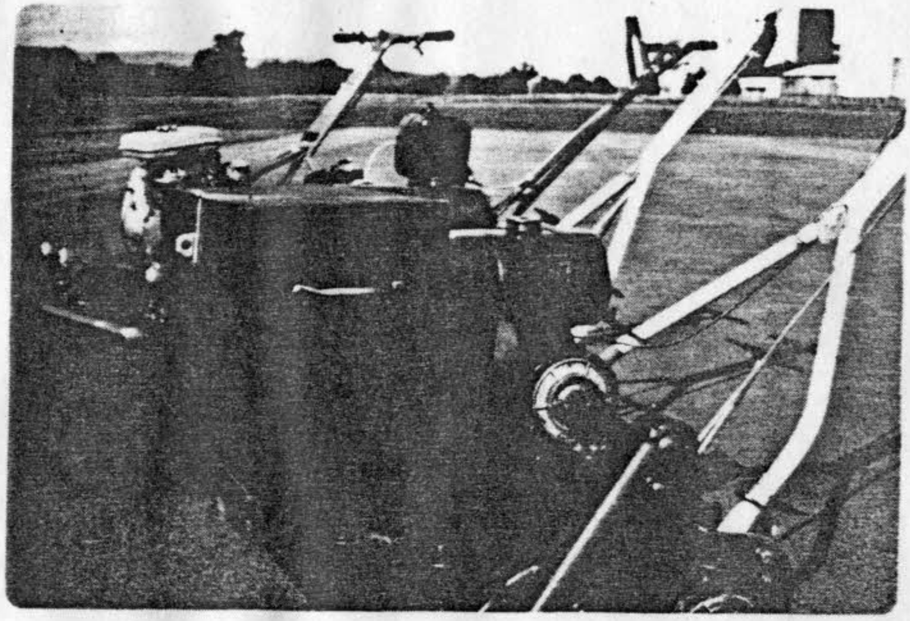

Figure 7. Jacobsen mower modified with frame and sand box weighing 70 pounds.

Figure 8. Rolling greens with modified Jacobsen mower.

Results and Discussion

Wetting Agent

The applied wetting agent gave the turf an oily appearance. However, the results showed no significant difference in speed on wetting agent and check plots at the 0.05 level. The greatest difference over five days was 0.2 ft (Table 4).

Table 4. Putting green speeds for five days following a wetting agent application on Penneagle creeping bentgrass mowed at 4/32 inch.

Treatment	Mean Putting Green Speed				
	Day 1	Day 2	Day 3	Day 4	Day 5
	ft				
Wetting Agent	9.7	9.7	9.5	9.5	9.7
Check	9.6	9.8	9.7	9.7	9.9

Water vs. No Water

Results of speed measurements taken at 1100 h, one hour before water application to watered plots, were nonsignificant on seven of ten dates. Significant differences did occur on 17, 19, and 20 July but watered treatments were only 0.5 ft slower than nonwatered treatments. On three of the ten days, water treatments were the same or faster than nonwater treatments (Figure 9).

Results of speed measurements taken at 1300 h, one hour after water application to watered plots, showed significant differences between treatments on five of six dates (Figure 10). However, water treatments were only 0.5 to 0.7 ft slower than nonwater treatments.

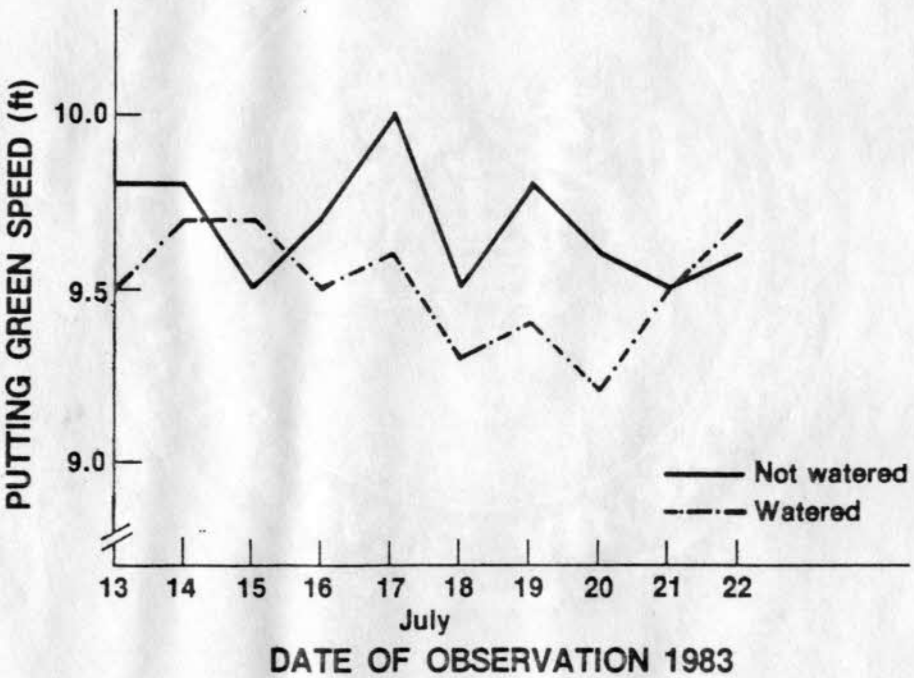

Figure 9. Putting green speeds on watered and nonwatered plots mowed at 4/32 inch. Measured at 1100 h, one hour before 0.3-inch irrigation to watered plots.

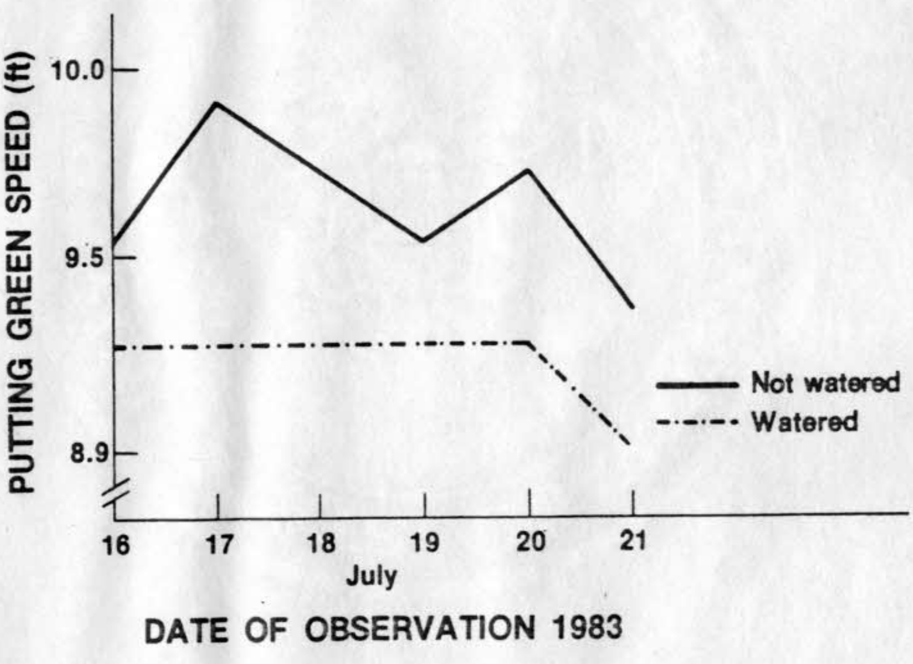

Figure 10. Putting green speeds on watered and nonwatered plots mowed at 4/32 inch. Measured at 1300 h, one hour after 0.3-inch irrigation to watered plots.

The speed on the nonwatered treatment did not increase over the 10 day period. It was 0.1 ft slower after ten days while the water treatment was 0.2 ft faster after ten days. Any significant increases on nonwatered plots were unjustified because patches of turf died after two weeks. Due to poor turf quality, no further experiments were conducted.

In summary, while surface water will initially decrease putting green speed, the residual is less than 24 hours. Also, nonwatered greens will not gradually increase in speed. Therefore, irrigation, if properly timed, can be used to maintain turf and not change putting green speed.

Rolling

The four and six consecutive days of single rolling were always significantly faster than the check. Increases ranged from 0.5 to 1.1 ft and were immediate but not cumulative (Table 5). Speeds within treatments were similar except when there was a transition from rolling to nonrolling. When rolling was stopped, speed returned to check levels within one or two days.

Double rolling significantly increased speed from 1 to 2 ft on all treatments (Table 6). The speed increase was immediate but not cumulative. Speeds within treatments were similar and change only occurred when there was a transition from rolling to nonrolling. Each time rolling ceased speed returned to check levels within two days.

Table 5. Putting green speeds for single rolling treatments for 2 to 6 consecutive days of rolling on greens mowed at 4/32 inch.

Consecutive Days of Single Rolling	Putting Green Speed					
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
	ft					
0	10.0 c†	10.0 c	9.9 b	9.7 b	9.9 c	10.0 b
2	<u>10.2</u> bc	<u>10.3</u> bc	10.0 b	9.9 b	10.0 c	9.7 b
4	<u>10.4</u> ab	<u>10.8</u> a	<u>10.6</u> a	<u>10.8</u> a	10.5 b	9.8 b
6	<u>10.5</u> a	<u>10.7</u> ab	<u>10.8</u> a	<u>10.6</u> a	<u>10.8</u> a	<u>10.6</u> a

†Means for a given date followed by the same letter are not significantly different at the 0.05 level.

Underlined number indicates a rolling treatment.

Table 6. Putting green speeds for double rolling treatments for 2 to 6 consecutive days of rolling on greens mowed at 4/32 inch.

Consecutive Days of Double Rolling	Putting Green Speed						
	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 8
	ft						
0	11.0 b†	10.3 b	10.1 c	10.2 b	10.9 c	10.3 b	9.9 a
2	<u>12.0</u> a	<u>11.5</u> a	10.7 b	10.6 b	10.9 c	10.2 b	
4	<u>12.2</u> a	<u>11.6</u> a	<u>12.1</u> a	<u>11.7</u> a	11.5 b	10.5 b	
6	<u>12.3</u> a	<u>11.7</u> a	<u>11.9</u> a	<u>11.8</u> a	<u>12.2</u> a	<u>11.5</u> a	10.2 a

†Means for a given date followed by the same letter are not significantly different at the 0.05 level.

Underlined number indicates a rolling treatment.

Rolling compressed and smoothed the turf canopy. This reduced friction and increased speed. By the next day the turgor pressure within the plants had caused them to return to an uncompressed state. Therefore, the speed increases do not last for more than one day.

TOPDRESSING

Materials and Methods

In the fall of 1982 a topdressing experiment using a Pennsylvania Glass Number 1 sand was designed with three treatments: 1) light frequent topdressing approximately 40 lbs/1000 ft^2, 2) spring and fall topdressing approximately 400 lbs/1000 ft^2, and 3) no topdressing. The weights of 40 and 400 lb. of sand were equivalent to approximately 0.4 and 4.0 ft^3, respectively. The sand analysis was 17.2% coarse, 73.1% medium, 7.2% fine, and 2.5% very fine. Each treatment was applied to 24 by 72 ft blocks. Within the blocks were 6 by 24 ft plots of Penncross, Penneagle, Emerald, and PSU-25 creeping bentgrass replicated three times. Speed measurements were only taken on Penncross and Penneagle. The area received approximately 2.5 lb N/1000 ft^2 per season. Refer to Appendix, Table 11, for dates of N application.

The light topdressing was applied with a Scott's broadcast fertilizer spreader while a Spread Lite topdressing machine was used for the heavy application. Hand watering was used to wash in topdressing.

Twelve light treatments were applied from 24 August to 8 November 1982 and 10 more light treatments were applied between 30 April and 19 August 1983. Heavy treatments were applied 20 October 1982 and 26 May 1983. Weekly speed readings were recorded throughout the 1983 season.

On 14 September 1983, 26 April, and 25 May 1984, the light and heavy treatments were aerified with 1/2 inch tines and the holes were filled with sand topdressing. Between 27 June and 29 August 1984, six light treatments were applied. Speed readings were recorded during the 1984 season.

An analysis of variance of the speeds was calculated for each date using a split block design.

Results and Discussion

The results were nonsignificant for treatments in 1983 at the 0.05 level (Figure 11). There was no variety difference or variety by treatment interaction. The mean speed for all three treatments was 7.5 ft. Penncross and Penneagle also had mean speeds of 7.5 ft. Lack of differences were thought to be caused by the 0.7 inch thatch layer measured on this turf stand. Aerification and vertical mowing in the fall of 1983 and spring of 1984 were implemented to reduce the thatch.

Analysis of the readings made during 1984 showed no significant treatment or variety differences or treatment by variety interaction (Figure 12). Mean speeds for light frequent, spring and fall, and check treatments were 8.0, 8.1, and 8.2 ft, respectively. Penncross and Penneagle had mean speeds of 8.2 and 8.0 ft, respectively.

These results were different than those found by Throssell (1981). He found an 8:1:1 sand, soil, and peat topdressing increased speed after eight days because it created a firmer surface. Since, the speeds measured from this topdressing study did not show treatment differences; the sand topdressing did not create a firmer surface.

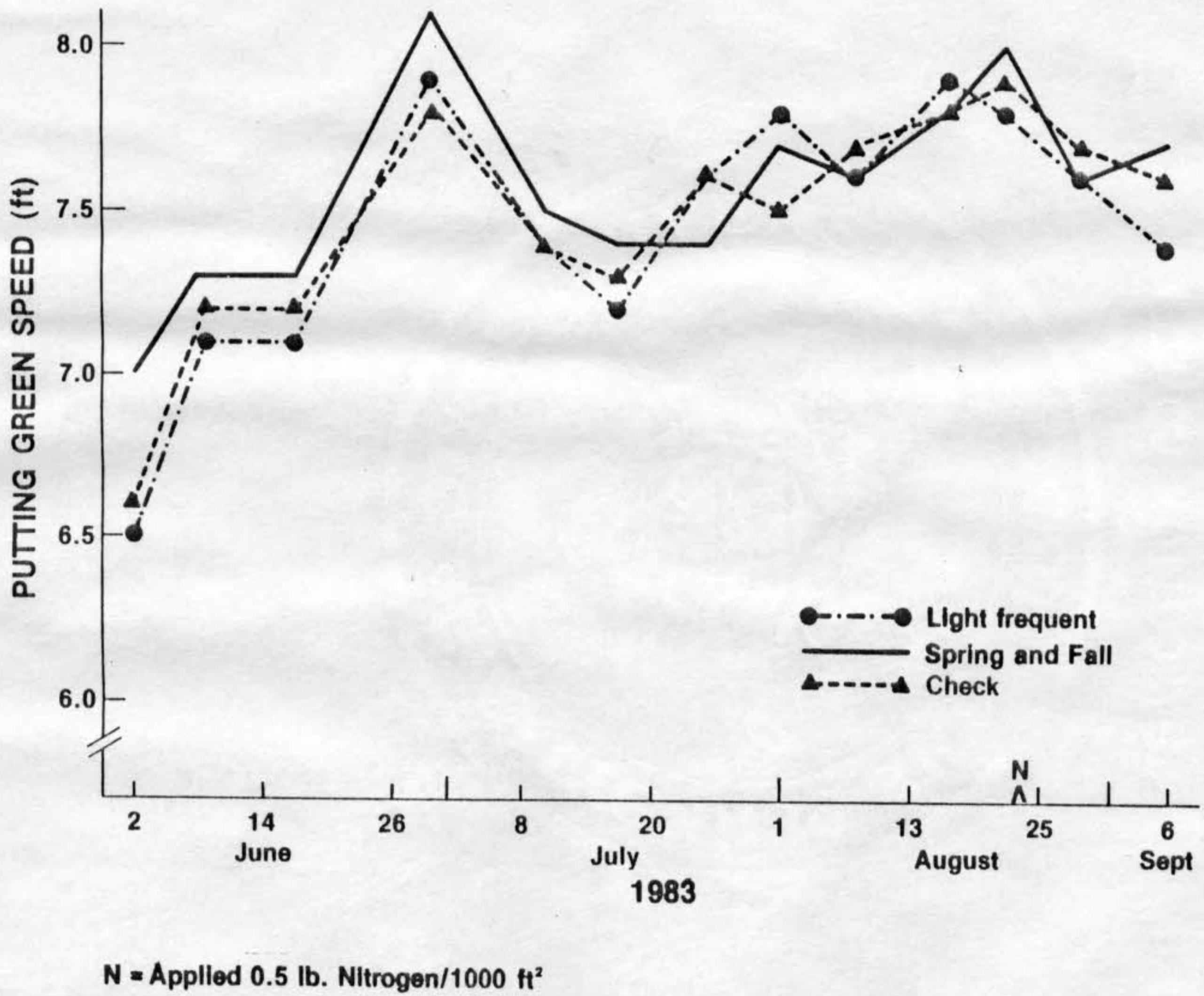

Figure 11. Effect of topdressing treatments on putting green speeds during 1983.

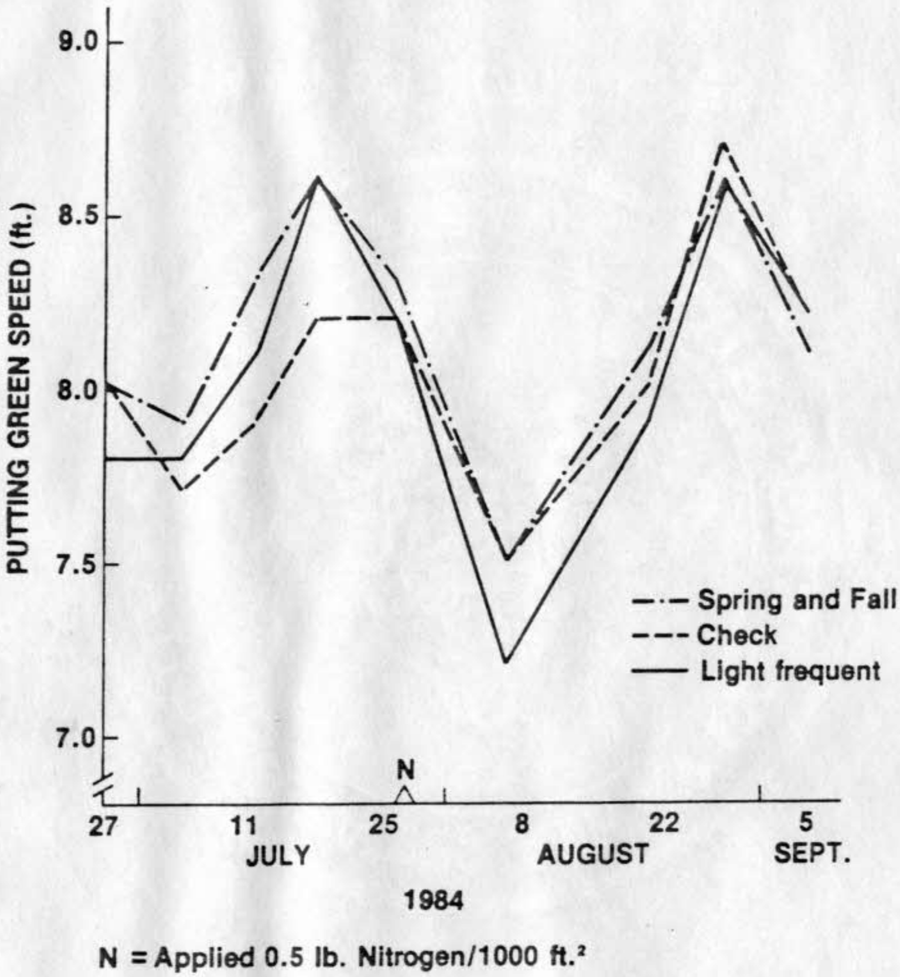

Figure 12. Effect of topdressing treatments on putting green speeds during 1984.

VARIETAL EVALUATION

Materials and Methods

In 1984 the seeded creeping bentgrass varieties were mowed six times a week at 5/32 inch with a Jacobsen Greens King.

Putting green speeds were measured on 22 seeded varieties. Variety plots were split for brush and check treatments. The rotary brush on a Bunton mower was set 1/8 inch below the roller surface and the bedknife was taken out of adjustment to eliminate mowing while brushing. Weekly treatments consisted of brushing in one direction, on 1/2 of the plots followed by perpendicular mowing. Four directions were alternated weekly. Brushing began five weeks before the first of four measurements. Speed readings for opposite directions were recorded and the difference between the directions was calculated.

Slopes varied on the plots, so a transit was used to determine the different elevations and the slope was used as a covariate during analysis of covariance.

Three analyses of variances were calculated: 1) differences in ball roll between opposite directions, 2) slopes of the green, and 3) putting green speed. A split block design with three replications was used for each analysis.

Results and Discussion

Brushing did not significantly affect the difference in speed measured in opposite directions at the 0.05 level (Table 7). There was no varietal difference and no variety by treatment interaction.

Table 7. The difference between opposite directions of putting green speed and the speeds of brushing and check treatments on 22 seeded varieties.

Variety	Putting Green Speed Difference of Opposite Directions		Putting Green Speed	
	Check	Brush	Check	Brush
	---feet---			
Penncross	2.0	1.6	8.8	8.6
Par 4	1.9	1.1	8.8	8.5
4423-B	1.8	1.0	8.8	8.7
113	1.8	1.7	8.5	8.7
11384-F	1.8	1.0	8.5	8.9
C-10	1.8	1.2	8.6	8.9
108-A	1.7	1.2	8.6	8.9
Par 1	1.6	0.7	8.5	8.5
Penneagle	1.6	0.8	8.3	8.3
Prominent	1.4	0.8	8.6	8.9
107	1.3	0.8	8.7	8.5
114	1.3	1.7	8.2	8.7
11384-D	1.2	0.5	8.5	8.7
Par 6	1.2	2.0	8.4	8.8
108-B	1.1	1.6	8.4	8.6
Seaside	1.1	1.5	8.5	8.9
4423	1.0	1.1	8.7	8.6
115	1.0	1.3	8.7	8.5
108-E	0.9	1.6	8.7	8.7
Par 3	0.9	0.6	8.5	8.3
126	0.7	0.8	8.2	8.7
105	0.6	1.5	8.6	8.6

The analysis of variance indicated that the effect of slope on speed was significant at the 0.05 level. When slope was used as a covariate, the analysis of covariance was not significant for treatments, varieties and treatment by variety interaction. Therefore, we did not succeed in increasing the speed uniformity of the surface with brushing. This may be due to the previous management of the surface. Because it was moderately fertilized, 2.5 lbs N/1000 ft^2, there was not much grain in any of the varieties. Therefore, brushing was ineffective.

There was no significant speed difference among varieties at the 0.05 level. The maximum difference between the variety means was 0.6 ft (Table 7). This value is similar to the 0.8 ft difference Throssell (1981) found on the same varieties. His mean speeds were approximately 0.5 ft slower because they were mowed a 1/32 inch higher.

DECELERATION

Materials and Methods

Putting green speed is actually a measure of the rate of golf ball deceleration. To determine if the rate of deceleration was constant on the same and different heights of cut, a 10-foot Stimpmeter, opposed to the standard 3-foot model, was obtained from the U.S.G.A. (Figure 13). It was marked in 0.5 ft increments, and one end was supported by a stand to form a 20 degree angle with the turf surface; the same angle at which the ball is released and rolled from using the standard Stimpmeter. The ball was released from 0.5 ft increments up to 5 ft. Beyond this point the ball acceleration caused bouncing upon reaching the turf surface. On 11 October 1984 measurements were taken on two heights of cut, 4/32 and 6/32 inch, using check plots of the verticut and brush experiment.

An analysis of variance was calculated on the means using a randomized block design. Duncan's multiple range test was used to separate mowing height means. Regression analysis was performed to determine if deceleration rates were uniform.

Results and Discussion

At 4/32 inch the ball roll distances were significantly greater than 6/32 inch from all release points at the 0.05 level (Figure 14). The difference between heights of cut increased as ball release moved higher on the Stimpmeter. Only a 0.45 ft difference occurred at the 0.5 ft release point while 2.2 and 5.4 ft differences occurred at the 2.5 and 5.0 ft release points, respectively.

Two linear regression equations were calculated to explain the relationship between increment height on the Stimpmeter and ball roll.

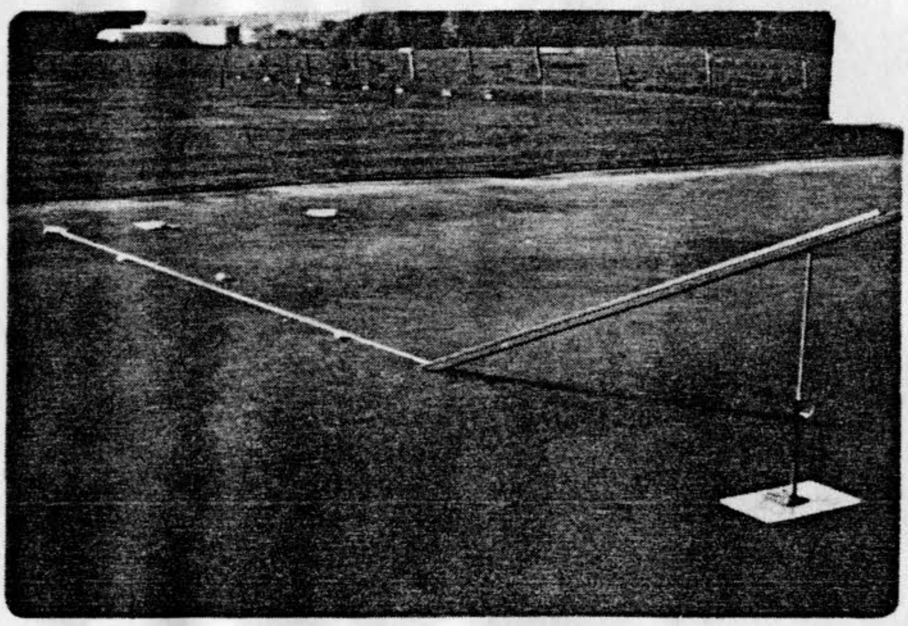

Figure 13. Measuring deceleration using a 10-foot Stimpmeter and supporting stand creating 20° angle at the putting surface.

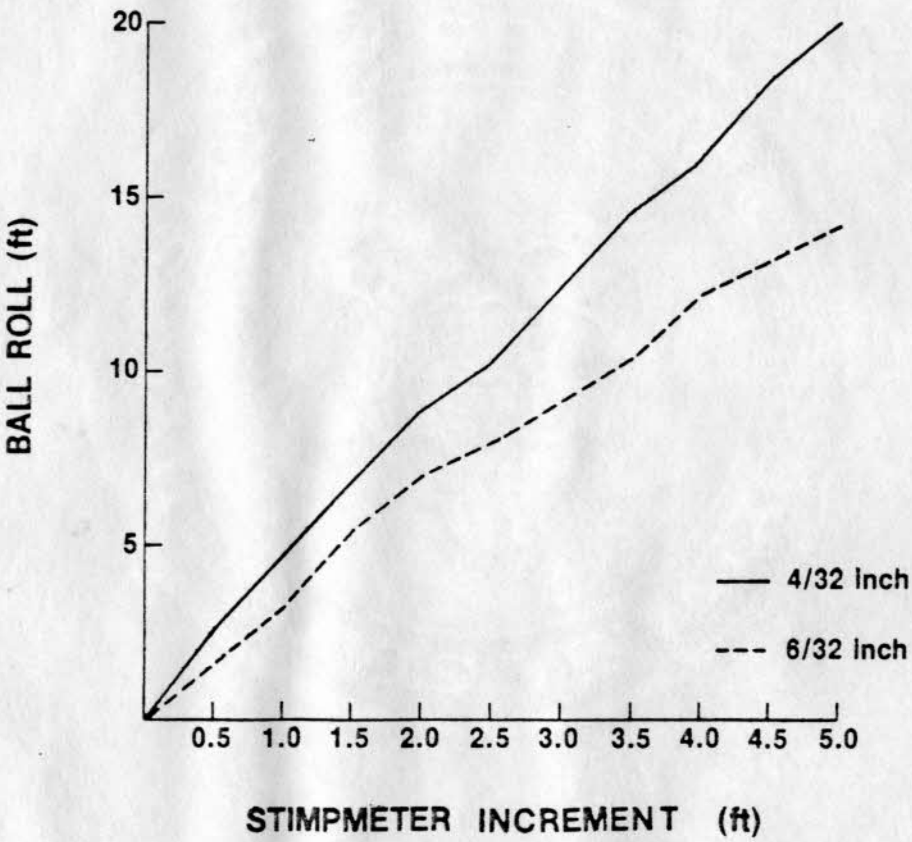

Figure 14. Distance of ball roll across greens mowed at 4/32 and 6/32 inch when the ball was released from 0.5-foot increments on a Stimpmeter at 20°.

The first was calculated on the means of the 4/32 inch height. The equation was $Y = 0.69 + (3.87)H$ with Y being the ball roll distance and H being the distance along the Stimpmeter from which the ball was released. This equation was highly significant with a highly significant r^2 value of 0.998. The C.V. was 1.8%.

Similarly, for the 6/32 height, the equation was $Y = 0.94 + (2.75)H$. This equation was also highly significant with a r^2 value of 0.995. The C.V. was 3.2%.

The linear relationship of these two equations indicates a constant deceleration rate for the two different mowing heights. However, the rate of deceleration differed between heights of cut. The deceleration rate was determined by the following equation:

$$a = v^2/2d \text{ (Semat, 1958)} \qquad [1]$$

where a = deceleration rate, v = initial velocity, and d = distance traveled.

Assuming that the friction on the Stimpmeter and air resistance is negligible, one can determine initial velocity on the green with the equation:

$$v = \sqrt{2gH} \text{ (Semat, 1958)} \qquad [2]$$

where v = velocity, g = acceleration due to gravity, and H = height above the surface from which the ball starts.

Substituting velocity into Eq. [1] one can determine the deceleration rate. An example of this procedure for the 4/32 inch would be:

$$v = \sqrt{2\ gH}$$

$$g = 32 \text{ ft/sec}^2$$

$$H = 1 \text{ ft}$$

$$v = \sqrt{2(32 \text{ ft/sec}^2)(1 \text{ ft})}$$

$$v = \sqrt{64\ ft^2/sec^2}$$

$$v = 8\ ft/sec$$

$$a = v^2/2d$$

$$a = 64\ ft^2/sec^2/2(19.9\ ft)$$

$$a = 1.61\ ft/sec^2$$

The deceleration rate for 4/32 and 6/32 heights of cut was 1.61 and 2.24 ft/sec^2, respectively. The ball speed decreased faster at 6/32 inch.

According to Newton's first law of motion, a body in motion will continue in motion with undiminished speed in a straight line as long as no unbalanced external force acts upon it. Since the ball does slow down there is an unbalance force acting upon it. The main force causing the deceleration rate is friction. The amount of friction each putting surface is applying to the golf ball is determined by the equation:

$$F = (W/g)(a) \quad \text{(Semat, 1958)} \qquad [3]$$

where F = friction, W = weight of the ball, g = force due to gravity, and a = rate of deceleration.

Since W and g are constants, the amount of friction is directly proportional to the rate of deceleration, or, the greater the deceleration the greater the friction of the surface and vice versa. Therefore, surfaces with less friction allow the ball to roll farther distances.

An interesting method of describing the speed of a surface is used in lawn bowling in Australia where the fastest green surfaces are the most desirable. Time in seconds is used as a measurement of green speed to roll a ball a fixed distance. On faster lawn bowling surfaces, less energy is required to get the ball to travel that distance. Since it initially has less energy it must have a lower deceleration rate or it could not travel the distance. We have shown fast greens have smaller deceleration rates than slow greens. Therefore, it takes the golf ball a longer time to come to a stop on the faster 4/32 inch surface. The time it takes the golf ball to come to a stop is determined by:

$$t = 2d/a \text{ (Baez 1967)} \qquad [4]$$

where t = time, d = distance the ball rolled, and a = deceleration rate. The time for 4/32 and 6/32 inch was 4.97 and 3.57 sec, respectively. Therefore, fast surfaces have less friction, causing smaller deceleration rates, which allows the ball to roll for a longer time.

COMPRESSION TESTING

Materials and Methods

The firmness of the canopy affects speed. It was measured by running compression tests with an Instron[3] (Figures 15 and 16). Using a two inch diameter plug sampler, 12 plugs were taken from the height of cut experiment, 24 plugs from the verticut and brushing experiment and 18 plugs from the topdressing experiment. Plugs were taken to the laboratory where the soil was cut off one inch below and parallel to the turf. The plugs were placed on the base plate with the turf end under the anvil. The Instron chart speed setting was two inches per minute and crosshead speed was 0.05 inches per minute. It was calibrated for 5 pound full scale and the crosshead displacement was determined. Under a given load the greater the crosshead displacement the greater the deformity of the surface.

An analysis of variance was calculated on the crosshead displacement for each experiment. A split block design was used on the topdressing and height of cut experiments. A 2 x 2 x 2 factorial design in a randomized complete block was used on the verticut and brushing experiment.

Results and Discussion

The results of the compression measurements on the different experiments will be discussed together. At all loads the measurements on the topdressing study were nonsignificant at the 0.05 level (Table 8). However, the light topdressing consistently deformed the least,

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[3]Instron is a testing device made by the Instron Corporation, Canton, Massachusetts.

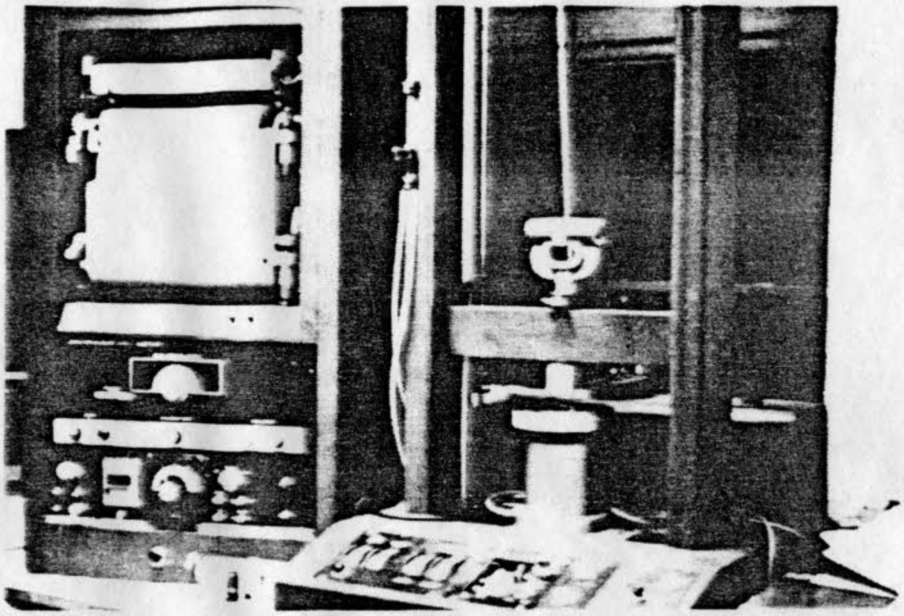

Figure 15. The Instron compression apparatus and chart.

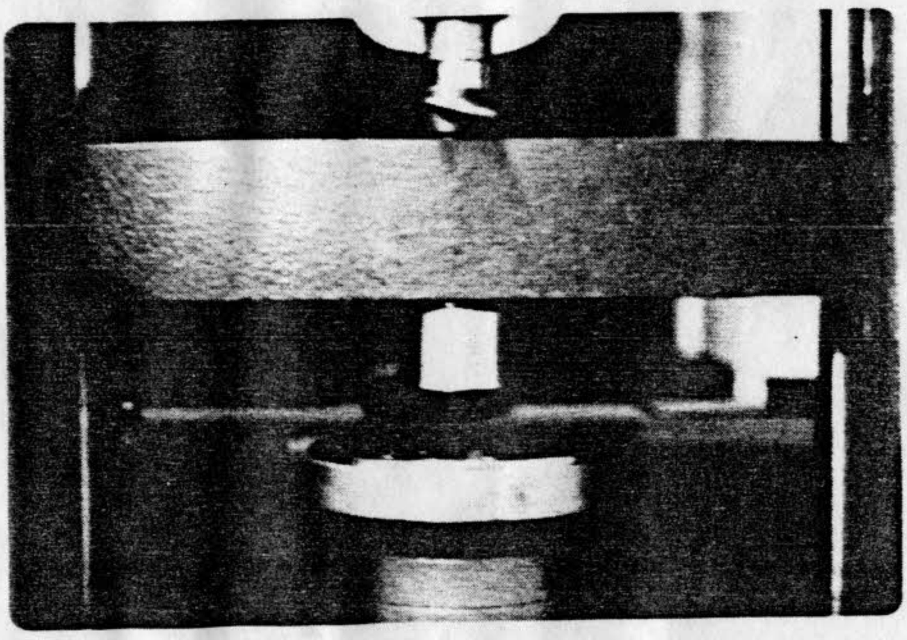

Figure 16. Instron base plate and anvil.

Table 8. Deformity measurements on topdressing treatments for 1- to 5-pound loads.

Load (lbs)	Deformity		
	Spring and Fall Topdressing	Check	Light Frequent Topdressing
	inch		
1	0.093	0.087	0.079
2	0.133	0.131	0.119
3	0.165	0.166	0.151
4	0.192	0.197	0.179
5	0.216	0.223	0.203

ranging from 0.079 to 0.203 inches while the spring and fall treatment and check were similar, approximately 0.090 to 0.220 inches. This indicated that continued light treatments may significantly firm the surface, causing a speed increase.

On the verticut and brushing experiment the lower height was significantly firmer at the 0.05 level (Table 9). The deformity of 4/32 inch ranged from approximately 0.080 to 0.165 inches while 6/32 inch ranged 0.115 to 0.230 inches. There were no significant differences between the treatments, suggesting the speed increases shown from verticutting were not the result of a firmer surface.

On the height of cut experiment 3/32 inch was significantly firmer than 6/32 inch at the 0.05 level (Table 10). The ranges were 0.080 to 0.181 inches and 0.103 to 0.241 inches for 3/32 and 6/32 inch, respectively.

Table 9. Deformity measurements on verticut and brush treatments at 4/32 and 6/32 inch heights of cut for 1- to 5-pound loads.

Load (lbs)	Deformity							
	4/32 inch				6/32 inch			
	Verticut	Brush	Verticut and Brush	Check	Verticut	Brush	Verticut and Brush	Check
	inch							
1	0.086 a†	0.075 a	0.084 a	0.079 a	0.118 b	0.111 b	0.110 b	0.122 b
2	0.112 a	0.104 a	0.116 a	0.105 a	0.155 b	0.154 b	0.146 b	0.164 b
3	0.134 a	0.126 a	0.141 a	0.127 a	0.182 b	0.189 b	0.174 b	0.196 b
4	0.150 a	0.146 a	0.160 a	0.143 a	0.205 b	0.217 b	0.199 b	0.224 b
5	0.165 a	0.163 a	0.178 a	0.159 a	0.225 b	0.239 b	0.218 b	0.247 b

†Means should be compared within rows and those with the same letter are not significantly different at the 0.05 level.

Table 10. Deformity measurements on 3/32 and 6/32 inch heights of cut for 1- to 5-pound loads.

Load (lbs)	Deformity	
	3/32 inch	6/32 inch
	------------------ inch ------------------	
1	0.080 a[†]	0.108 b
2	0.113 a	0.152 b
3	0.139 a	0.187 b
4	0.161 a	0.216 b
5	0.181 a	0.241 b

[†]Means should be compared within rows and those with the same letter are not significantly different at the 0.05 level.

The values from the Instron between experiments show similarities. Mowing heights of 3/32 inch and 4/32 inch are similar. All 6/32 inch values are similar. Although a correlation could not be determined, because there were not enough heights of cut in the experiment, the author feels that the firmness of the lower heights of cut enhances speed. Firmer surfaces have less rolling friction (Weber et al., 1952). Future studies should be designed with more cutting heights.

SUMMARY AND CONCLUSIONS

The purpose of this research was to determine the effect some management variables have on putting green speed. Other objectives were to determine firmness of the turf canopy and find whether deceleration rates are uniform on different surfaces.

The speed experiments were conducted at the Joseph Valentine Turfgrass Research Center at The Pennsylvania State University in University Park, Pennsylvania. Management practices studied were verticutting, brushing, mowing height, wetting agent, water management, rolling, topdressing, and varietal evaluation. Speeds were measured using a Stimpmeter following directions from the Stimpmeter Instruction Booklet (U.S.G.A., 1979).

To determine firmness, 2-inch diameter plugs were removed from the mowing height, verticut and brushing, and topdressing experiment areas, and taken to the lab. An Instron compression apparatus was used to record the amount each plug deformed under a weight of 1 to 5 pounds. A 10-foot Stimpmeter marked in 0.5 foot increments was used to determine deceleration rates on plots mowed at 4/32 and 6/32 inch. It was supported by a stand to create a 20° angle with the turf surface, the same angle of ball release of the regular Stimpmeter. After releasing balls from the different increments the distance of roll was measured and plotted. The data showed a linear relationship, and these data were then used to determine deceleration rates. Individual summaries are presented for each management practice, firmness, and deceleration experiments.

Verticutting and Brushing

Verticutting increased speed 0.5 to 1.2 ft on plots mowed at 6/32 inch. The increase was immediate but did not last for more than 6 days suggesting weekly treatments are necessary to maintain speed. Verticutting X brushing was similar to verticutting. This increase is equivalent to that obtained by a 1/32 inch decrease in mowing height. Brushing did not differ from the check.

Verticutting did not increase speed on plots mowed at 4/32 inch in 1983 but it did increase speed 0.4 to 1.2 ft in 1984. Verticutting X brushing was similar to verticutting alone while brushing was similar to the check.

Varietal Height of Cut

Mowing height had the largest impact on speed. Speed increases of 2 ft were recorded as mowing height was lowered from 6/32 to 4/32 inch. However, lowering the height to 3/32 inch resulted in only a 0.3 ft additional increase. Average speed was 7.8, 9.7, and 10.0 ft for 6/32, 4/32, and 3/32 inch, respectively. Since lower mowing heights decrease turf density the 0.3 ft increase was not justified. There was no difference daily or seasonally between Penncross and Penneagle at any height of cut.

Spring speeds were the slowest, increasing during the season. Seasonal variations of 3.2 and 2.5 ft were recorded on the 4/32 and 3/32 inch areas, respectively, in 1983. The variation was largely due to management. Once the turf is actively growing, factors that stimulated growth or allowed for shoot lengthening decreased speed. Nitrogen applications and skipped mowings caused the major speed decreases.

Wetting Agent

Wetting agent did not change the speed of the greens.

Water vs. No Water

Watered plots, 0.3 inches the previous day, were not significantly slower than nonwatered plots 7 of 10 days. There was only a 0.5 to 0.7 ft decrease from watering 1 hour after treatment. The average speed did not change over ten days with either treatment. Therefore, properly timed irrigation can be used to maintain turf and not change speed.

Rolling

Single and double rolling increased speed 0.5 to 1.1 ft and 1 to 2 ft, respectively. On both treatments there was an immediate but nonaccumulative increase and speeds returned to check levels within two days after treatments were discontinued. Rolling compressed the turf canopy. By the next day the turgor pressure within the plants had caused them to return to an uncompressed state. Therefore, rolling can be used to get an immediate speed increase but it must be done daily to maintain desired speeds.

Topdressing

Sand topdressing did not change speed after 28 light frequent or five heavy applications.

Varietal Evaluation

Brushing did not increase uniformity on 22 seeded creeping bentgrass varieties. There was only a 0.6 ft speed difference between varieties and a range of 8.2 to 8.8 ft.

Deceleration

Linear deceleration rates of 1.6 to 2.2 ft/sec^2 were determined for 4/32 and 6/32 inch mowing heights, respectively. As expected increased friction caused the higher deceleration rate. Also it was determined that high deceleration rates reduced the time it took a ball to roll a fixed distance. Therefore, to alter putting green speed, change the rate of deceleration by altering the friction of the surface.

Compression Testing

Results of Instron compression tests were not significantly different for the topdressing treatments; however, there was a nonsignificant trend for light frequent topdressing plugs to consistently deform less than the other treatments. The 3/32 and 4/32 inch mowing heights were deformed less than the 6/32 inch height. The increase in surface rigidity contributes to speed increases on lower heights of cut.

BIBLIOGRAPHY

Beard, J. 1973. Turfgrass: Science and Culture. Prentice-Hall, Inc., Englewood Cliffs, NJ. p. 217.

Bengeyfield, B. 1982. The art of yesterday the science of today. U.S.G.A. Green Section Record 20(2):2-3.

Dudeck, A. E. and C. H. Peacock. 1981. Effects of several overseeded ryegrasses on turf quality, traffic tolerance, and ball roll. p. 75-81. In R. W. Sheard (ed.) Proc. 4th International Turfgrass Res. Conf., Ontario Agric. Col., Univ. Guelph and Int. Turfgrass Soc., Guelph, Ontario.

Engel, R. E., A. M. Radko, and J. R. Trout. 1980. Influence of mowing procedures on roll speed of putting greens. U.S.G.A. Green Section Record 12(1):7-9.

Grau, F. V. 1933. Drift and speed of putted ball on bents as determined by mechanical putter. The Bulletin of the U.S.G.A. Green Section 13(3):74-81.

Hoos, D. 1982. The Green Section's Stimpmeter: Most think friend some think enemy. U.S.G.A. Green Section Record 20(4):9-10.

Monteith, J., Jr. 1929. Testing turf with a mechanical putter. The Bulletin of the U.S.G.A. Green Section 9(1):3-6.

O'Brien, P. M. 1981. The Stimpmeter--A management tool. U.S.G.A. Green Section Record 19(2):28-29.

Radko, A. M. 1978. How fast are your greens?--An update. U.S.G.A. Green Section Record 16(2):20-21.

Radko, A. M. 1984. The Stimpmeter--A perspective. U.S.G.A. Green Section Record 22(5):12-13.

Radko, A. M., R. E. Engel, and J. R. Trout. 1981. A study of putting green variability. U.S.G.A. Green Section Record 19(1):9-13.

Semat, H. 1958. Physics in the Modern World. Rhinehart and Company, Inc., NY. p. 43-50.

Stimpson, E. 1937. Introducing the Stimp. Golfdom. 11(2):40-41, 44.

Thomas, F. 1978. The Stimpmeter and the open. U.S.G.A. Green Section Record 16(6):7-9.

Throssell, C. S. 1981. Management factors affecting putting green speed. M.S. Thesis. The Pennsylvania State University.

United States Golf Association. 1979. Stimpmeter instruction booklet. Golf House: Far Hills, NJ.

Weber, R., M. White, and K. Manning. 1952. College Physics. McGraw-Hill Book Company, Inc., NY. p. 70-80.

Zontek, S. 1983. Up with the Stimpmeter. U.S.G.A. Green Section Record 20(4):16-17.

APPENDIX: Additional Tables

Table 11. Fertilizer dates, rates, and materials used on putting green speed research area.

Dates	Rates	Material	Speed Areas Applied
	(lbs N/1000 ft^2)		
4/27/83	0.25	Peters 30-10-10	All
5/6/83	0.25	Peters 30-10-10	All
5/24/83	0.75	Scott's 22-0-16	All
8/23/83	0.50	Scott's 22-0-16	All
9/26/83	0.50	Scott's 22-0-16	Verticut and brush, variety height of cut, and seeded varieties
	0.75	Scott's 22-0-16	Penneagle block
4/26/84	0.75	Scott's 22-0-16	All
5/17/84	0.50	Peters 30-10-10	All but topdressing
5/31/84	0.50	Scott's 22-0-16	All
7/28/84	0.50	Peters 30-10-10	All
9/13/84	0.50	Scott's 22-0-16	All

Table 12. Mean temperature and growing degree days for the 1983 growing season in University Park, Pennsylvania, in F°.

DATE	MAY	DD†	JUNE	DD	JUL	DD	AUG	DD	SEPT	DD	OCT	DD
1	65	5	59	-	70	10	80	20	65	5	52	-
2	65	5	52	-	75	15	73	13	68	8	60	0
3	65	5	58	-	78	18	72	12	69	9	61	1
4	58	-	64	4	80	20	75	15	71	11	64	4
5	51	-	62	2	79	19	73	13	72	12	67	7
6	45	-	67	7	68	8	76	16	75	15	60	0
7	54	-	68	8	58	-	74	14	78	18	54	-
8	67	7	60	0	65	5	77	17	65	5	55	-
9	48	-	57	-	70	10	79	19	66	6	59	-
10	41	-	61	1	65	5	72	12	69	9	50	-
11	49	-	68	8	64	4	70	10	79	19	49	-
12	54	-	70	10	69	9	67	7	78	18	55	-
13	56	-	74	14	77	17	61	1	63	3	63	3
14	59	-	74	14	72	12	60	0	53	-	58	-
15	64	4	75	15	76	16	63	3	54	-	50	-
16	57	-	76	16	81	21	68	8	56	-	48	-
17	40	-	74	14	81	21	72	12	58	-	49	-
18	46	-	75	15	80	20	74	14	58	-	56	-
19	53	-	72	12	77	17	73	13	64	4	46	-
20	55	-	69	9	76	16	77	17	72	12	47	-
21	63	3	65	5	75	15	75	15	73	13	43	-
22	59	-	65	5	74	14	72	12	56	-	43	-
23	57	-	69	9	67	7	77	17	46	-	42	-
24	61	1	73	13	67	7	72	12	47	-	47	-
25	52	-	73	13	70	10	72	12	49	-	50	-
26	59	-	64	4	68	8	75	15	51	-	43	-
27	50	-	70	10	72	12	77	17	55	-	43	-
28	50	-	79	19	73	13	75	15	63	3	44	-
29	55	-	68	8	78	18	73	13	56	-	56	-
30	59	-	67	7	77	17	71	11	44	-	36	-
31	63	3			78	18	74	14			37	-
	55.2	33	67.3	242	72.6	402	72.3	389	62.7	170	51.0	15

†DD = growing degree days using 60°F as the base temperature.

Table 13. Mean temperature and growing degree days for the 1984 growing season in University Park, Pennsylvania, in F°.

DATE	MAY	DD†	JUNE	DD	JUL	DD	AUG	DD	SEPT	DD	OCT	DD
1	63	3	53	-	67	7	71	11	63	3	50	-
2	48	-	62	2	64	4	76	16	66	6	46	-
3	51	-	63	3	70	10	73	13	70	10	48	-
4	47	-	63	3	71	11	67	7	66	6	54	-
5	50	-	66	6	72	12	73	13	56	-	50	-
6	47	-	71	11	65	5	70	10	54	-	51	-
7	49	-	73	13	68	8	74	14	53	-	49	-
8	51	-	75	15	59	-	74	14	54	-	49	-
9	52	-	78	18	59	-	77	17	65	5	54	-
10	46	-	77	17	65	5	76	16	66	6	60	0
11	52	-	78	18	70	10	74	14	67	7	62	2
12	62	2	71	11	75	15	72	12	70	10	57	-
13	57	-	74	14	71	11	70	10	62	2	57	-
14	55	-	77	17	74	14	74	14	67	7	56	-
15	47	-	67	7	76	16	70	10	63	3	57	-
16	45	-	55	-	76	16	70	10	49	-	53	-
17	43	-	61	1	71	11	73	13	49	-	55	-
18	52	-	60	0	72	12	68	8	52	-	61	1
19	51	-	73	13	65	5	70	10	54	-	60	0
20	66	6	70	10	65	5	66	6	59	-	64	4
21	64	4	67	7	70	10	62	2	65	5	61	1
22	64	4	64	4	67	7	64	4	60	0	63	0
23	71	11	68	8	68	8	68	8	63	3	55	-
24	60	0	73	13	76	16	65	5	66	6	51	-
25	63	3	63	3	70	10	62	2	74	14	50	-
26	71	11	62	2	65	5	63	3	67	7	62	2
27	65	5	63	3	68	8	66	6	50	-	66	6
28	65	5	69	9	60	0	70	10	46	-	69	9
29	60	0	69	9	65	5	70	10	42	-	68	8
30	57	-	71	11	65	5	73	13	47	-	50	-
31	48	-			67	7	72	12			58	-
	55.3	54	67.2	248	68.3	258	70.3	313	59.1	100	58.8	36

†DD = growing degree days using 60°F as the base temperature.

Table 14. Speeds from the verticut and brushing experiment.

	6/32 inch				4/32 inch			
Date	Check	Brush	Verticut	Brush and Verticut	Check	Brush	Verticut	Brush and Verticut
	feet							
6/2/83	7.6	7.5	7.9	8.2	8.9	9.1	9.0	9.0
6/9	7.6	7.5	7.5	8.1	9.2	9.3	8.9	9.3
6/17	7.2	7.4	7.7	8.1	9.1	9.3	9.2	9.5
7/1	7.6	7.6	8.0	8.2	9.6	9.8	9.8	9.9
7/11	7.5	7.5	8.5	8.2	10.4	10.2	10.6	10.1
7/18	7.5	7.5	7.6	8.1	9.7	9.5	9.6	9.5
7/26	8.1	8.2	8.8	8.9	10.4	10.2	10.7	10.5
8/2	8.0	7.9	8.1	8.4	10.1	10.0	10.1	10.4
8/9	7.5	7.7	8.0	8.3	10.1	10.3	10.5	9.9
8/18	7.8	7.9	8.6	8.7	9.7	9.8	10.0	10.2
8/30	7.4	7.5	8.2	8.1	9.8	9.9	10.2	10.2
9/6	7.1	7.1	7.7	8.2	9.2	9.7	9.2	9.6
5/2/84	7.1	7.3	7.6	7.6	9.1	9.6	9.6	9.4
5/10	7.1	6.9	7.8	8.0	8.4	8.8	8.9	9.0
5/18	7.2	7.0	7.8	7.8	8.9	9.1	9.4	9.3
5/24	7.2	7.1	8.2	8.2	9.3	9.3	9.9	9.8
6/1	7.7	7.8	8.5	8.4	9.9	10.1	11.0	10.3
6/8	7.1	7.2	8.0	7.9	9.1	9.4	9.9	9.7
6/15	7.6	7.5	8.2	8.4	9.6	10.3	10.4	10.5
6/22	8.2	8.1	8.8	8.9	10.6	10.4	11.6	11.2
6/27	8.0	8.0	9.1	9.7	10.0	9.8	11.0	11.3
7/6	8.1	8.2	9.0	8.8	9.8	9.9	10.3	10.5
7/13	8.1	8.4	9.0	9.0	10.6	10.7	11.0	10.8
7/19	8.1	8.1	9.3	9.1	10.6	10.3	11.2	11.0
7/26	8.3	8.4	9.2	9.3	10.9	10.7	12.0	11.8
8/6	7.1	7.3	7.5	7.7	8.7	9.1	9.5	9.2
8/20	8.0	8.2	8.8	8.6	10.3	10.3	10.4	10.5
8/24	8.3	8.4	9.4	9.2	10.6	10.6	11.7	11.1
8/27	7.9	8.0	8.9	9.1	10.8	10.6	11.1	11.2
8/31	8.4	8.5	9.4	9.1	10.3	10.3	10.8	10.5
9/12	8.2	8.3	8.9	9.0	10.3	10.6	10.7	10.8
9/18	7.8	8.2	9.5	8.9	10.2	10.5	10.8	10.9
9/27	8.4	8.4	9.5	9.7	10.5	10.6	11.1	11.2

Table 15. Speeds from the varietal height of cut experiment.

Date	Height of Cut 3/32	4/32	6/32	Varieties Penncross	Penneagle
	------------	------------	feet	------------	------------
6/7/83	8.9	8.3	7.3	8.1	8.3
6/14	9.8	9.0	7.9	8.8	9.0
6/29	9.6	9.4	8.0	8.9	9.1
7/5	9.9	9.6	7.8	9.1	9.1
7/12	10.6	10.2	7.8	9.6	9.5
7/18	9.3	9.3	7.6	8.8	8.7
7/26	10.3	10.5	8.4	9.7	9.8
8/2	9.3	10.0	7.8	8.9	9.1
8/9	9.9	9.9	7.9	9.2	9.2
8/18	10.0	9.5	8.2	9.3	9.2
8/23	11.0	10.7	8.2	10.1	9.8
8/30	10.3	10.9	8.1	9.8	9.7
9/6	9.8	9.6	7.3	8.9	9.0
9/14	11.0	11.3	8.4	10.3	10.2
9/23	10.7	10.5	8.1	9.8	9.7
10/3	9.1	8.1	7.0	8.1	8.0
10/11	11.1	9.4	7.5	9.4	9.3
10/20	11.4	9.1	7.6	9.4	9.3
5/2/84	9.4		7.3	8.6	8.9
5/10	8.8		7.1	8.0	8.0
5/18	9.3		7.3	8.4	8.5
5/24	9.2		7.5	8.4	8.4
6/1	10.2		7.5	8.8	8.8
6/8	9.3		7.1	8.1	8.1
6/15	10.1		7.7	8.5	8.7
6/22	10.3		8.0	8.8	8.9
6/27	9.7		7.9	8.6	8.4
7/6	9.1		7.6	8.1	8.0
7/13	9.9		7.8	8.7	8.4
7/19	9.8		8.1	8.8	8.6
7/26	10.3		8.3	9.0	8.9
8/6	8.6		7.2	7.5	7.4
8/20	9.5		7.7	8.6	8.0
8/27	10.0		7.9	8.8	8.4
9/5	9.9		7.9	8.8	8.3
9/12	10.3		7.8	9.1	9.0
9/18	9.7		8.2	9.1	8.8
9/27	10.7		8.3	9.6	9.3
10/4	10.6		8.6	9.6	9.6

Table 16. Speeds from the topdressing experiment.

Date	Topdressing Treatments			Varieties	
	Light Frequent	Check	Spring & Fall	Penncross	Penneagle
	---------------------------- feet ----------------------------				
6/2/83	6.8	6.7	7.0	6.7	6.9
6/9	7.2	7.1	7.3	7.2	7.2
6/17	7.3	7.3	7.4	7.2	7.5
7/1	7.8	7.9	8.0	7.9	7.8
7/11	7.5	7.5	7.5	7.5	7.5
7/18	7.2	7.4	7.3	7.3	7.3
7/26	7.6	7.5	7.5	7.5	7.5
8/2	8.0	7.7	7.6	7.7	7.9
8/9	7.6	7.7	7.6	7.6	7.6
8/18	7.9	7.7	7.8	7.8	7.8
8/23	7.8	7.8	7.8	7.9	7.7
8/30	7.5	7.7	7.6	7.6	7.6
9/6	7.4	7.5	7.4	7.6	7.3
6/27/84	7.8	8.0	8.0	7.9	7.9
7/6	7.8	7.7	7.9	7.9	7.6
7/13	8.1	7.9	8.3	8.1	8.1
7/19	8.6	8.2	8.6	8.5	8.4
7/26	8.2	8.2	8.3	8.3	8.2
8/6	7.2	7.5	7.5	7.6	7.2
8/20	7.9	8.1	8.1	8.1	7.9
8/27	8.6	8.7	8.6	8.8	8.5
9/5	8.2	8.2	8.1	8.3	8.0

Table 17. The range of coefficient of variation (CV) for each experiment.

Putting Green Speed Experiment	Range of CV
Verticut and brushing	1.26 - 4.97%
Varietal height of cut	0.93 - 6.25%
Topdressing	0.79 - 4.08%
Wetting agent	1.59 - 3.88%
Watering	2.24 - 4.62%
Rolling	2.33 - 4.15%
Varieties	3.53 - 4.08%
Instron compression	2.07 -12.16%