## SUMMARY AND CONCLUSIONS

- Ball roll was not affected by vertical mowing frequency treatments.
- Ball roll decreased with increasing mowing height in both years.
- Putting speed rated fast in 1989 and medium-fast in 1990 at the 4.8 mm mowing height.
- Ball roll decreased from zero to four days after vertical mowing application, then increased from four to six days after vertical mowing in 1989.
- Ball roll decreased from zero to eight days after vertical mowing application in 1990.
- Color and quality ratings were not affected by vertical mowing frequency treatments.
- Color and quality ratings increased with increasing mowing height.
- Color and quality ratings increased from zero to eight days after vertical mowing application in 1990.
- The normalized difference vegetation index was not affected by vertical mowing frequency treatments.
- Vegetation index values increased with increasing mowing height.
- Root production in 1989 was not affected by mowing height or vertical mowing frequency treatments.
- Root production at two sampling depths in 1990 increased with

increasing mowing height.

- Canopy temperatures were slightly higher at 2 than at 0 and 1 X month$^{-1}$ vertical mowing treatment.
- Canopy temperatures decreased with increasing mowing height on one date in each year.

Based on the relatively fast and medium-fast putting speeds observed at the highest mowing height in 1989 and 1990, recommending higher mowing heights on putting greens can be justified. Golf course superintendents can obtain acceptable putting speed at relatively high mowing heights by maintaining a sound management program. Lowering the mowing height to increase putting speed causes the turfgrass to undergo physiological changes that increase its susceptibility to environmental stresses such as temperature and drought. Although vertical mowing at the frequencies studied did not affect any of the parameters measured, future research should address more frequent vertical mowing using greens conditioners or groomers since many turfgrass managers experiment with these. Traffic should be incorporated into future investigations to simulate actual playing conditions. The Stimpmeter was useful in determining treatment differences and should be used in future putting green studies. Spectral radiometry data seems useful in delineating slight differences in turfgrass color

## References

Aase, J.K., and F.H. Siddoway. 1980. Determining winter wheat stand densities using spectral reflectance measurements. Agron J. 72:149-152

Albaugh, J. 1983. A new turf menace. USGA Green Section Rec. 21(2):11-12.

Beard, J.B. 1973. Turfgrass: science and culture. Prentice-Hall, Inc., Englewood Cliffs, N.J.

Beard, J.B. 1982. Turfgrass management for golf courses. Burgess Publishing Co. Minneapolis, MN.

Beard, J.B. and W.H. Daniel. 1965. Effect of temperature and cutting on the growth of creeping bentgrass (Agrostis palustris Huds.) roots. Agron J. 57:249-250

Beard, J.B. and W.H. Daniel. 1966. Relationship of creeping bentgrass (Agrostis palustris Huds.) root growth to environmental factors in the field. Agron. J. 58:337-339.

Beard, J.B. and W.H. Daniel. 1967. Variations in the total, nonprotein, and amide nitrogen fractions of Agrostis palustris Huds. leaves in relation to certain environmental factors. Crop Sci. 7:111-115.

Brede, A.D. 1990. Measuring green speed on sloped putting greens. USGA Green Section Rec. November/December 1990. pp.10-12.

Buchanan, B. 1984. Putting green management for quality and speed. Proceedings, 23rd Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 15-17.

Celis-Ceusters, A.M. 1980. Ground truth radiometry (Exotech) on bare and overgrown Belgian soils. Pedologie 30(1):43-66.

Chalmers, D.R. 1984. Putting green management for quality and speed. Proceedings, 23rd Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 13-14.

Chalmers, D.R. 1986. Putting green quality-How far can you go? Proceedings, 25th and 26th Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 64-66.

Goss, R.L., and A.G. Law. 1967. Performance of bluegrass varieties at two cutting heights and two nitrogen levels. Agron. J. 59:516-518.

Hankley, T. 1984. Putting green management for quality and speed. Proceedings,

23rd Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 20-21.

Hoos, D.D. 1982. The green section's Stimpmeter: Most think friend-some think enemy. USGA Green Section Rec. July/August 1982 pp.9-10

Horst, G.L., J.C. O'Toole, and K.L. Faver. 1989. Seasonal and species variation in baseline functions for determining crop water stress indices in turfgrass. Crop Sci. 29:1227-1232.

Idso, S.B. 1982. Non-water stressed baselines: A key to measuring and interpreting plant water stress. Agric. Meteorol. 27:59-70.

Idso, S.B., R.D. Jackson, P.J. Pinter Jr., R.J. Reginato, and J.L. Hatfield. 1981. Normalizing the stress degree day parameter for environmental variability. Agric. Meteorol. 24:45-55.

Jackson, R.D. 1982. Canopy temperature and crop water stress in Advances in Irrigation. D.Hillel ed. 1:43-85.

Jackson, R.D., P.J. Pinter, R.J. Reginato, and S. Idso. 1980. Hand held radiometry. Agric.Rev.Man.West.Ser. (U.S. Dept. Agric. Sci. Edu. Adm.) ARMW-19, pp.1-66

Johnson, B.J. 1986. Response to vertical mowing and ethofumesate treatments for annual bluegrass control in bermudagrass turf. Agron. J. 78:495-498.

Kinzer, B. 1990. Proper grooming of your turf. Grounds Maintenance. January 1990. pp.42-

Koski, A.J. 1983. Seasonal rooting characteristics of five cool-season turfgrasses. M.S. Thesis. The Ohio State Univ., Columbus.

Krans, J.V. and J.B. Beard. 1985. Effects of clipping on growth and physiology of 'Merion' Kentucky bluegrass. Crop Sci. 25:17-20.

Leamer, R.W., J.R. Noriega, and C.L. Wiegand. 1978. Seasonal changes in reflectance of two wheat cultivars. Agron. J. 70:113-118.

Lo, C.P. 1986. Applied Remote Sensing. Longman Scientific and Technical. New York, N.Y.

Madison, J.H. 1960. The mowing of turfgrass. I. The effect of season, interval, and height of mowing on the growth of seaside bentgrass turf. Agron. J. 52:449-452.

Madison, J.H. 1962. Turfgrass Ecology: Effects of mowing, irrigation, and nitrogen

treatments of Agrostis palustris Huds., 'Seaside' and Agrostis tenuis Sibth., 'Highland' on population, yield, rooting, and cover. Agron. J. 54:407-412

Mazur, A.R., and D.F. Wagner. 1987. Influence of aeration, topdressing, and vertical mowing on overseeded bermudagrass putting green turf. HortSci. 22(6):1276-1278.

Mitchell, R.V. 1983. It's a good tool-Use with caution and restraint. USGA Green Section Rec. 21(2):13-16.

O'Brien, P.M. 1983. Management trends in the Mid-Atlantic region. Proceedings, 22nd Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 34-35.

Owens, R. 1984. Putting green management for quality and speed. Proceedings, 23rd Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 18-19.

Rosenburg, N.J., B.L. Blad, and S.B. Verma. 1983. Microclimate: The biological environment. Wiley-Interscience: John Wiley and Sons, Inc., New York, N.Y.

SAS Institute, Inc. 1985. SAS User's Guide: Statistics, Version 5 ed. SAS Inst.,

Inc., Cary, NC. 956 pp.

Shearman, R.C., and J.B. Beard. 1973. Environmental and Cultural Preconditioning effects on the water use rate of Agrostis palustris Huds. cultivar Penncross. Crop Sci. 13:424-427.

Shoulders, J.F. 1983. Essential cultivation techniques on greens. Proceedings, 22nd Virginia turfgrass conference and trade show. Virginia Polytech. Inst. and state Univ. pp. 36-37.

Stahnke, G.K., and J.B. Beard. 1981. The effect of cultural practices on the surface speed of closely mowed greens. Texas Turfgrass Research-1979-80. PR-3843. pp. 60-63.

Steel, R.G.D. and J.H. Torrie. 1980. Principles and procedures of statistics. 2nd ed. Mc Graw-Hill, New York.

Thomas, F.W. 1983. Ups and downs with the Stimpmeter: How it all began. USGA Green Section Rec. 21(2):10-11.

Thompson, W.R., JR., and C.Y. Ward. 1965. Evaluation of management practices in controlling thatch accumulation on Tifgreen bermudagrass golf green turf. *In*

Agronomy abstracts, ASA, Madison, WI.

Throssell, C.S., R.N. Carrow, and G.A. Milliken. 1987. Canopy temperature based irrigation scheduling indices for Kentucky bluegrass turf. Crop Sci. 27:126-131.

Turgeon, A.J. 1991. Turfgrass management. Prentice-Hall, Inc. Englewood Cliffs, N.J.

Welterlen, M.S. and T.L. Watschke. 1981. Techniques for thermocouple placement and the automation of temperature measurements in the microenvironment of Kentucky bluegrass. Agron J. 73:808-812

White, R.H., and R. Dickens. 1984. Thatch accumulation in bermudagrass as influenced by cultural practices. Agron. J. 76:19-22.

Youngner, V.B., and F.J. Nudge. 1976. Soil temperature, air temperature, and defoliation effects on growth and nonstructural carbohydrates of Kentucky bluegrass. Agron. J. 68:257-260.

Zontek, S.J. 1983. Up with the Stimpmeter. USGA Green Section Rec. 21(2):16-17.

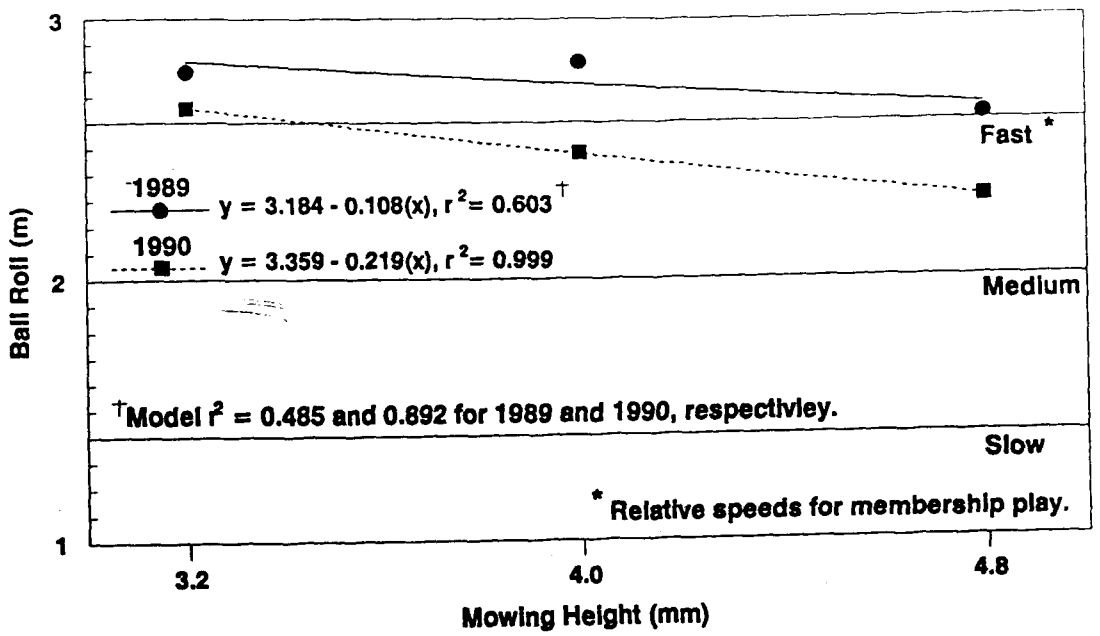



Figure 3. Average 1989 and 1990 stimpmeter readings as a function of mowing height, on a creeping bentgrass putting green.

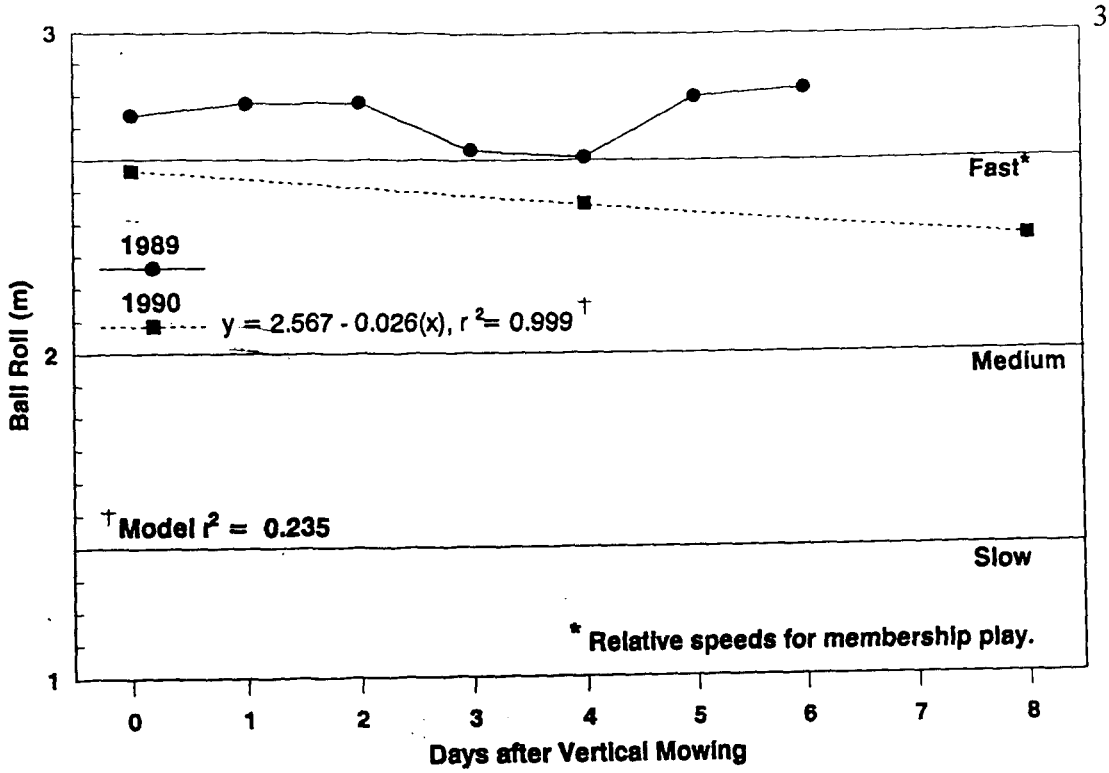
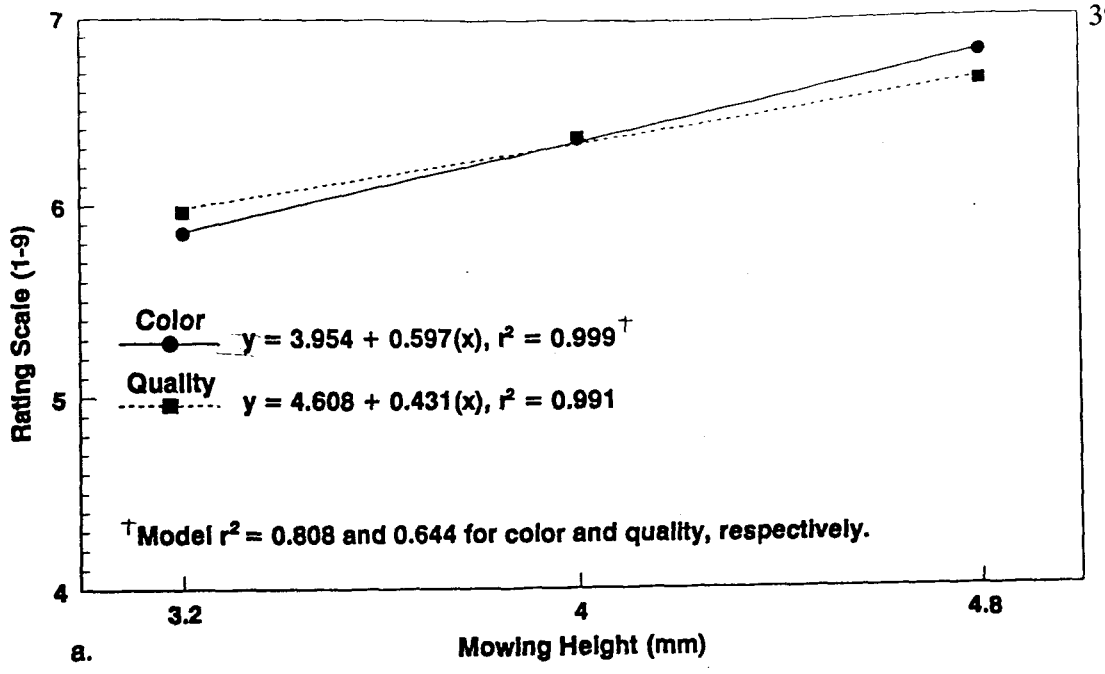



Figure 4. Average 1989 and 1990 stimpmeter readings, measured after vertical mowing treatment application.



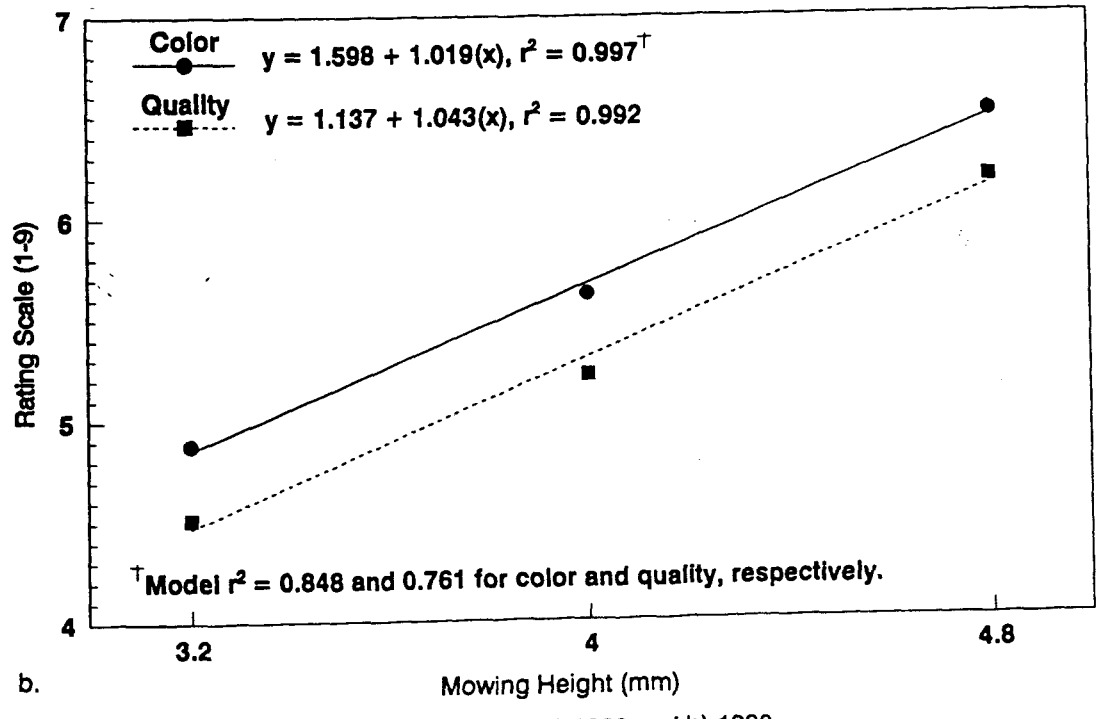




Figure 5. Average color and quality ratings for a) 1989 and b) 1990 as functions of mowing height.

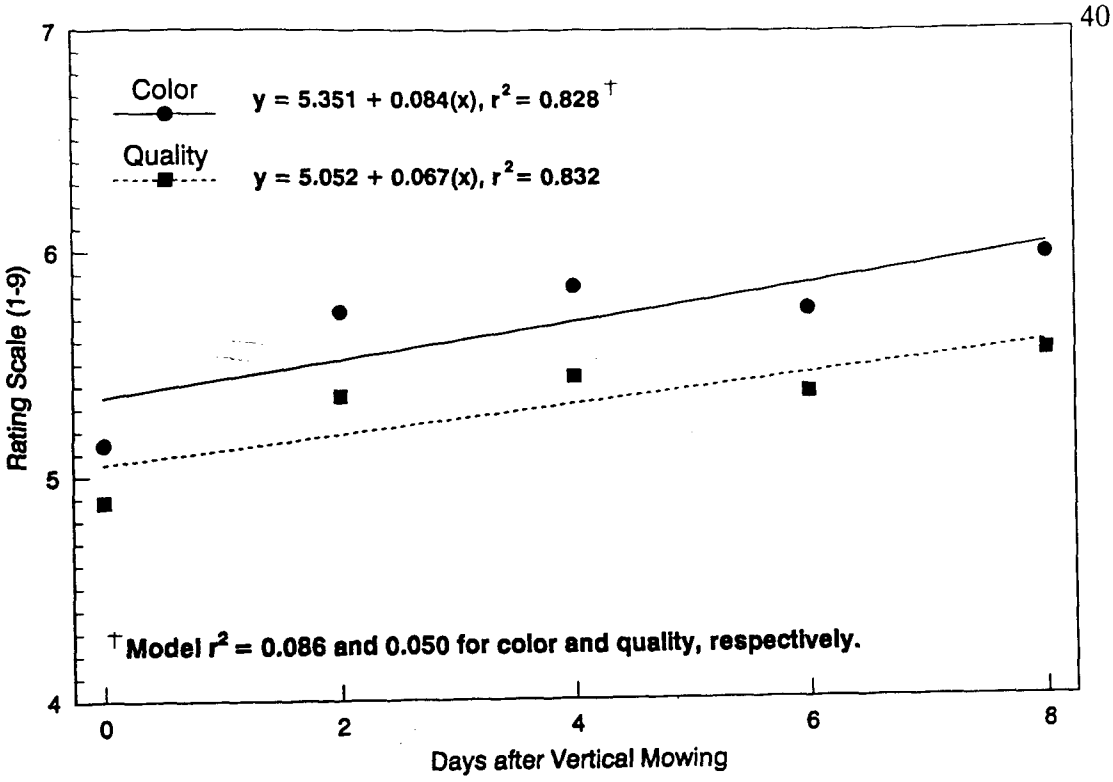



Figure 6. Average 1990 color and quality ratings as a function of time (i.e. days after vertical mowing application).

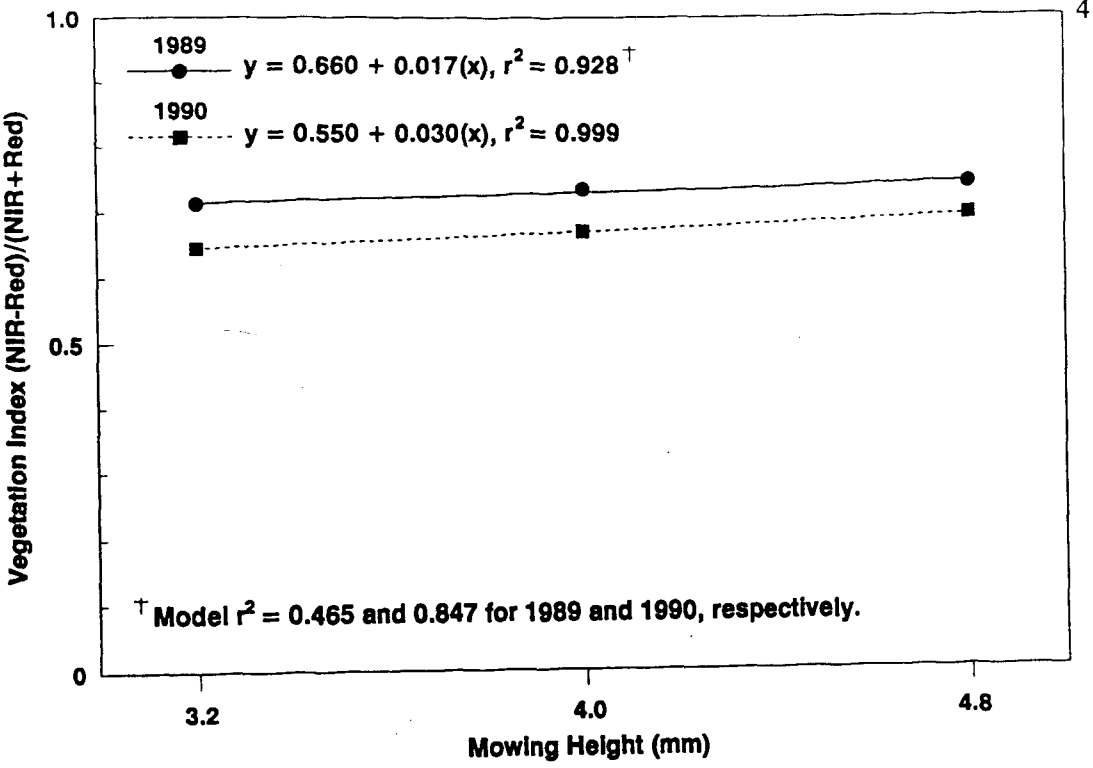



Figure 7. Normalized difference vegetation index averages as a function of mowing height for 1989 and 1990.
Vegetation index values were calculated from red and near-infrared (NIR) spectral band reflectances.

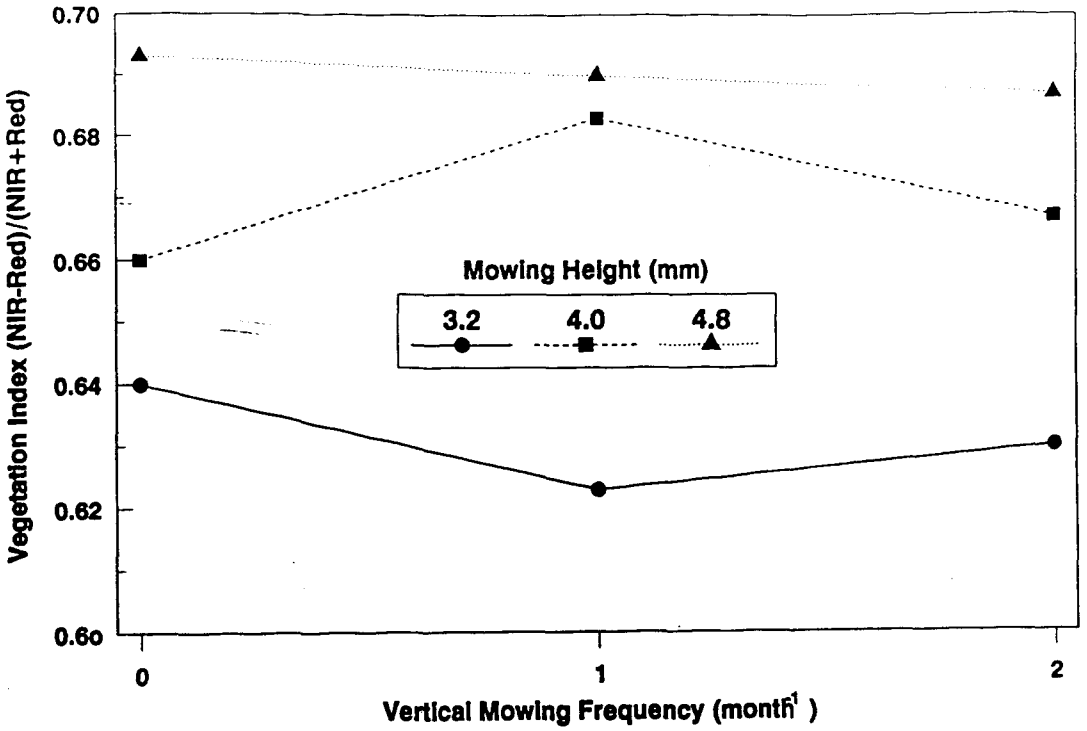



Figure 8. Mowing height x vertical mowing frequency interaction on the normalized difference vegetation index measured on 8 August 1990. Vegetation index values were calculated from red and near-infrared (NIR) spectral band relectances.

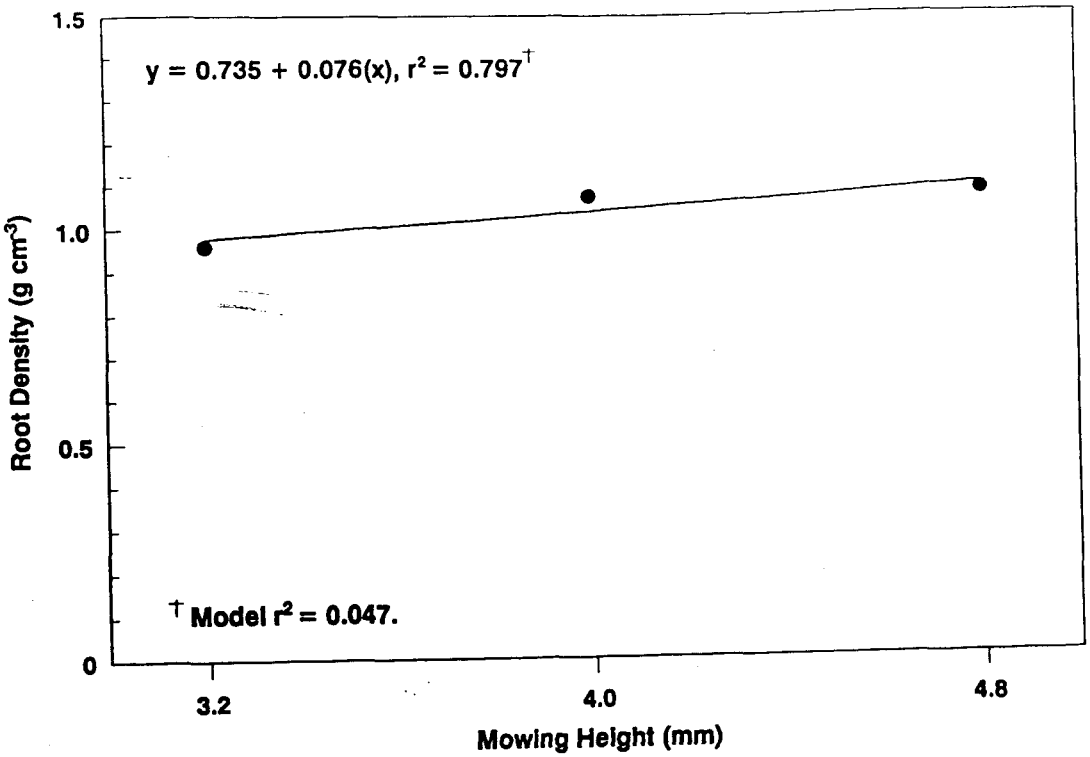



Figure 9. Creeping bentgrass root production at 76-152 mm soil depth as a function of mowing height, sampled 12 July 1990.

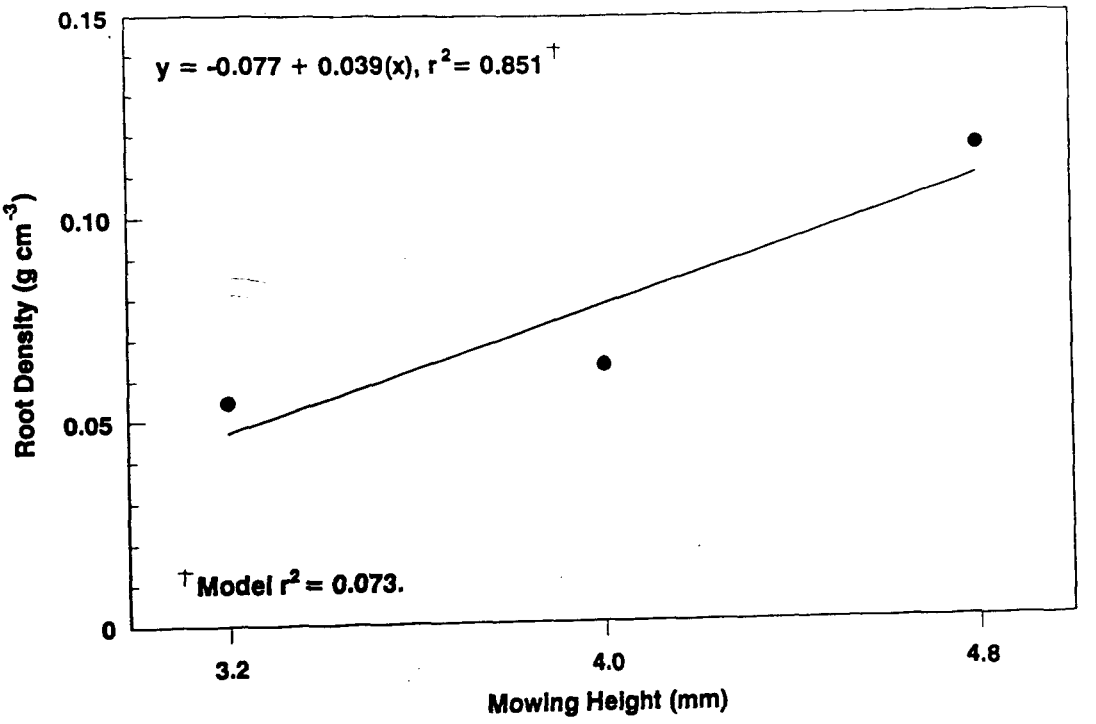



Figure 10. Creeping bentgrass root production at 152-228 mm soil depth as a function of mowing height, sampled 12 Sept. 1990.

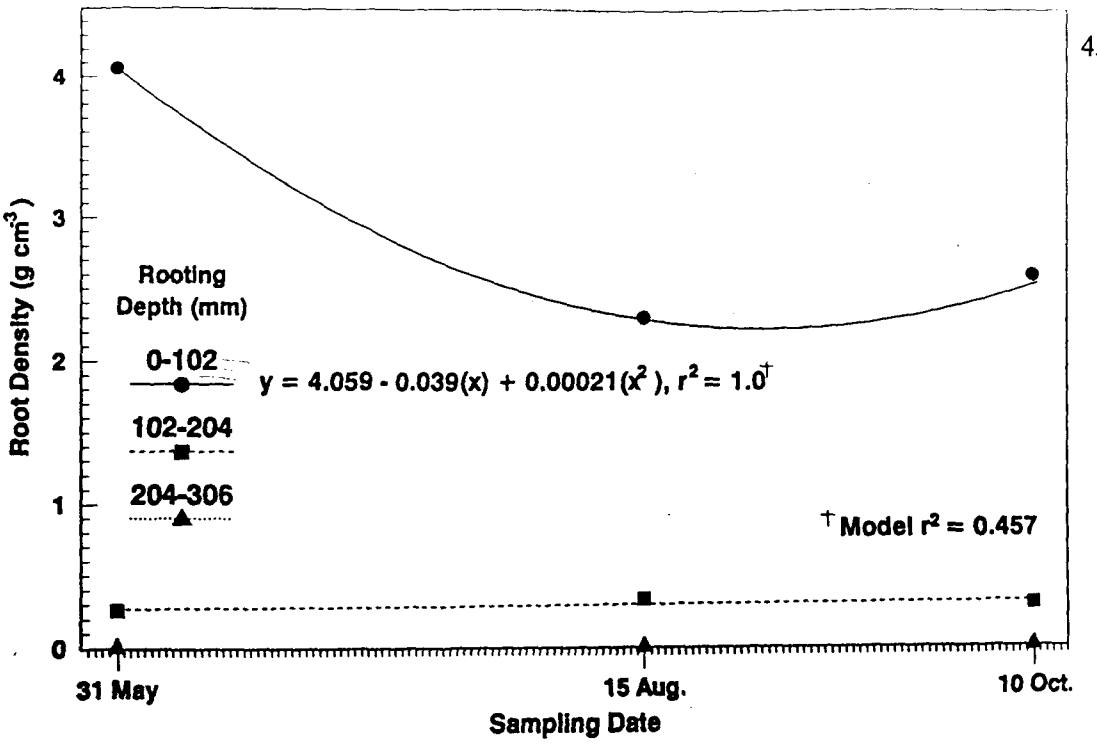



Figure 11. Creeping bentgrass root production at three rooting depths, sampled three times in 1989.

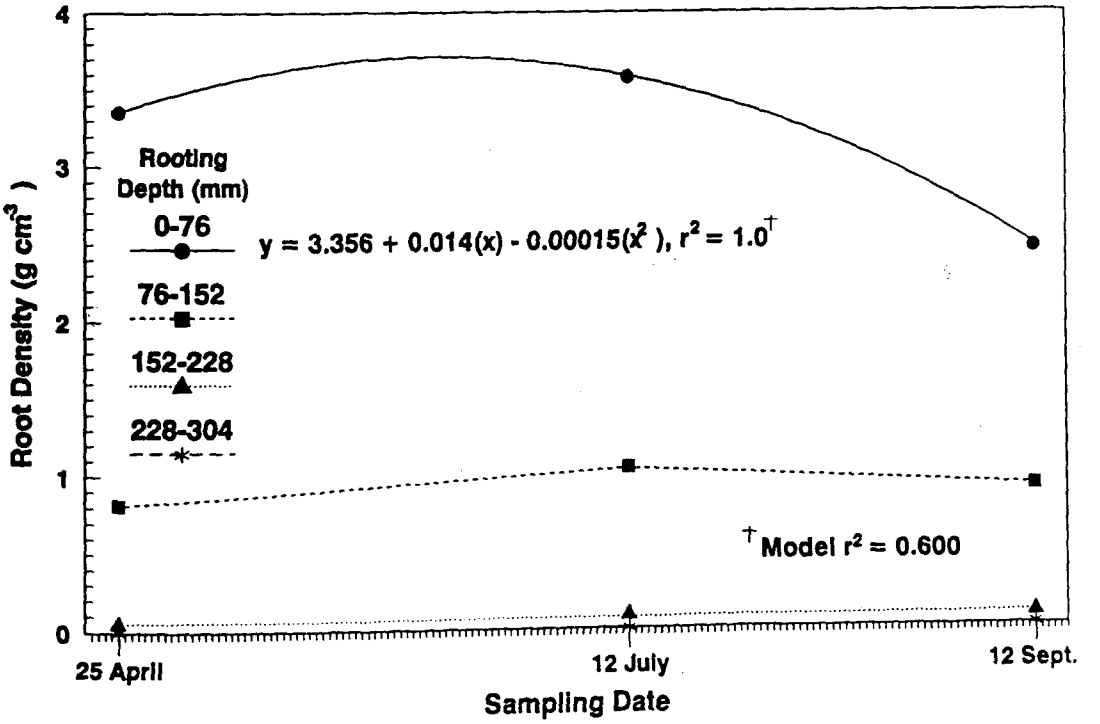
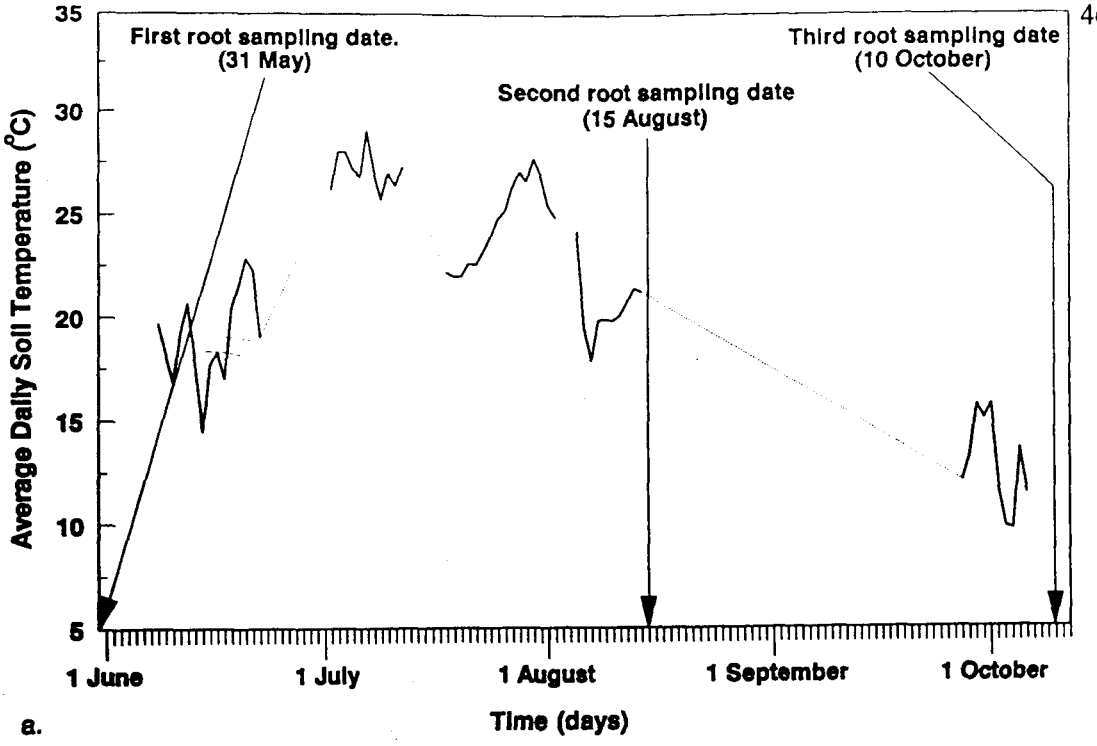
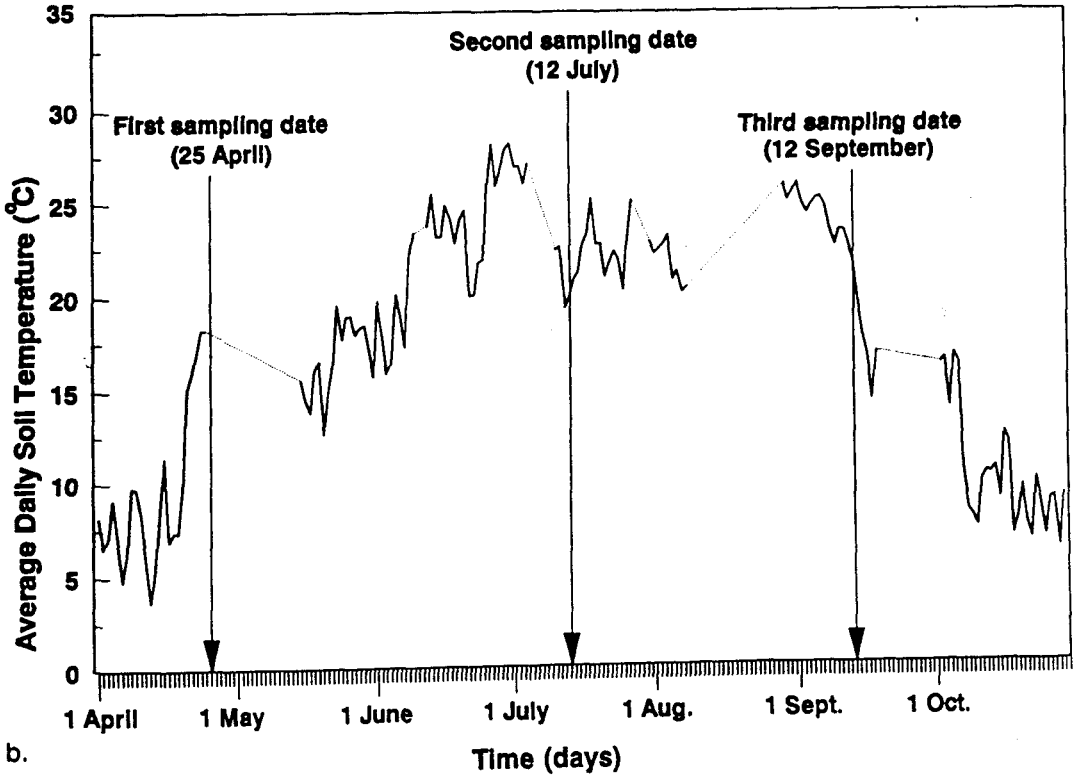



Figure 12. Creeping bentgrass root production at four rooting depths, sampled three times in 1990.

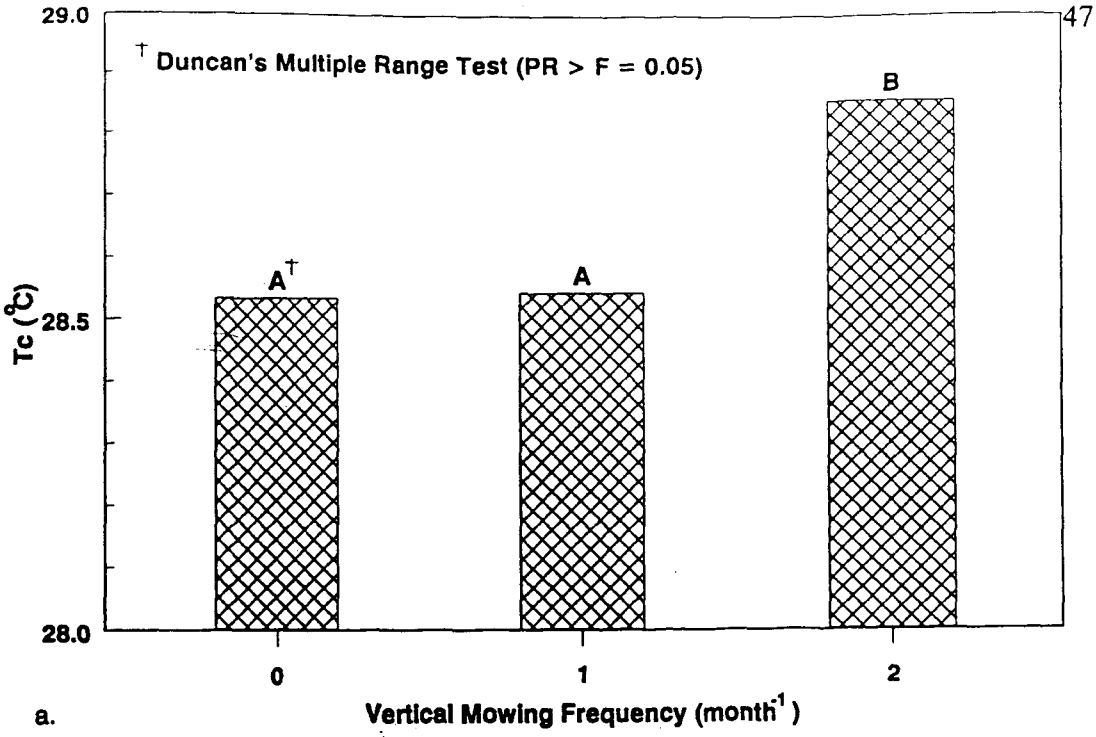



a.

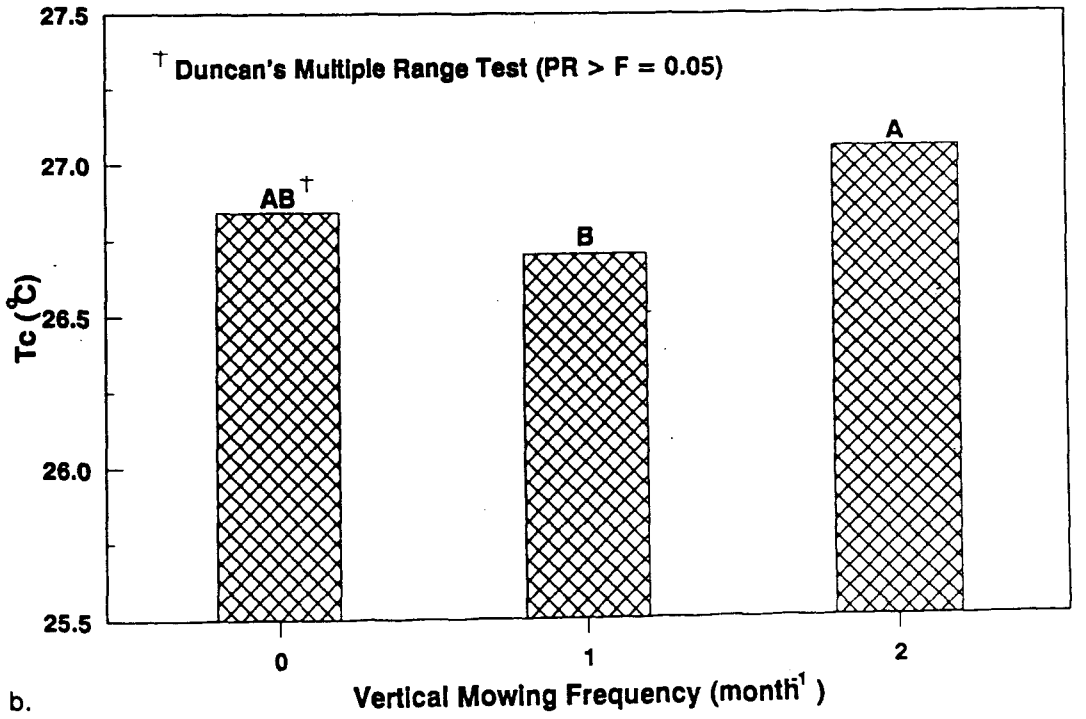



b.

Figure 13. Average daily soil temperatures at 2.54 cm depth during a) 1989, and b) 1990. Missing data indicated by dotted lines.




a.




b.

Figure 14. Vertical mowing frequency effects on creeping bentgrass canopy temperature measured a) 16 June 1989 and b) 18 May 1990.

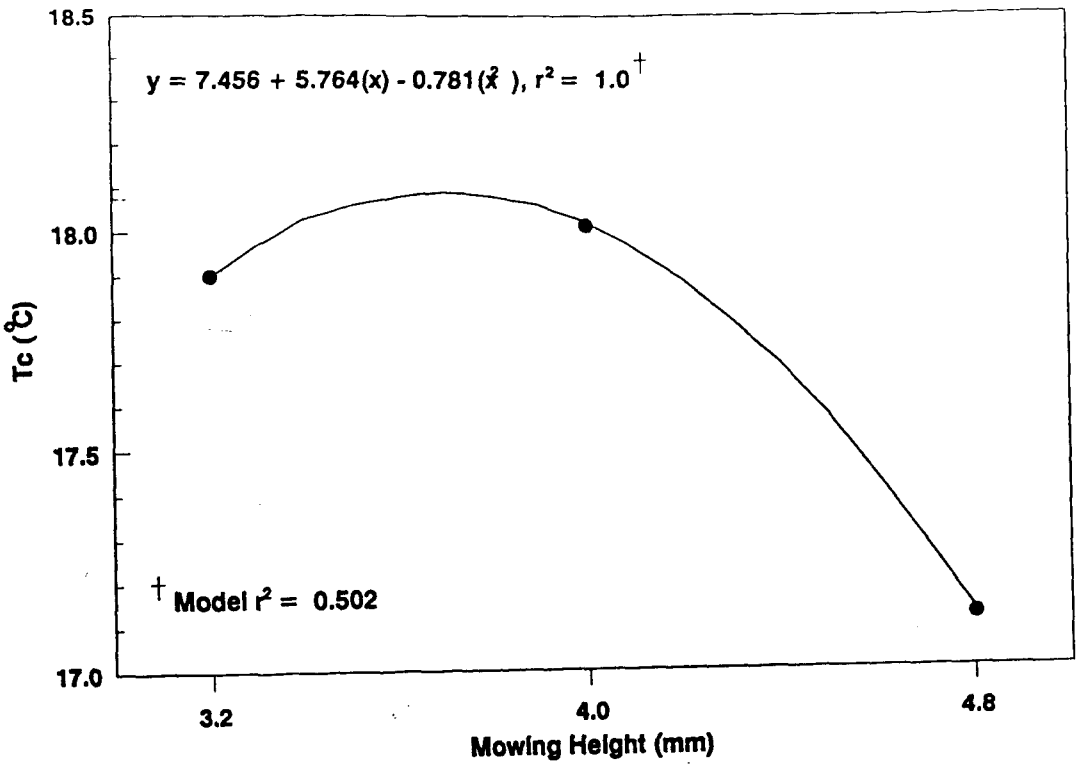



Figure 15. Creeping bentgrass canopy temperatures (Tc) as a function of mowing height, measured 14 June 1989.

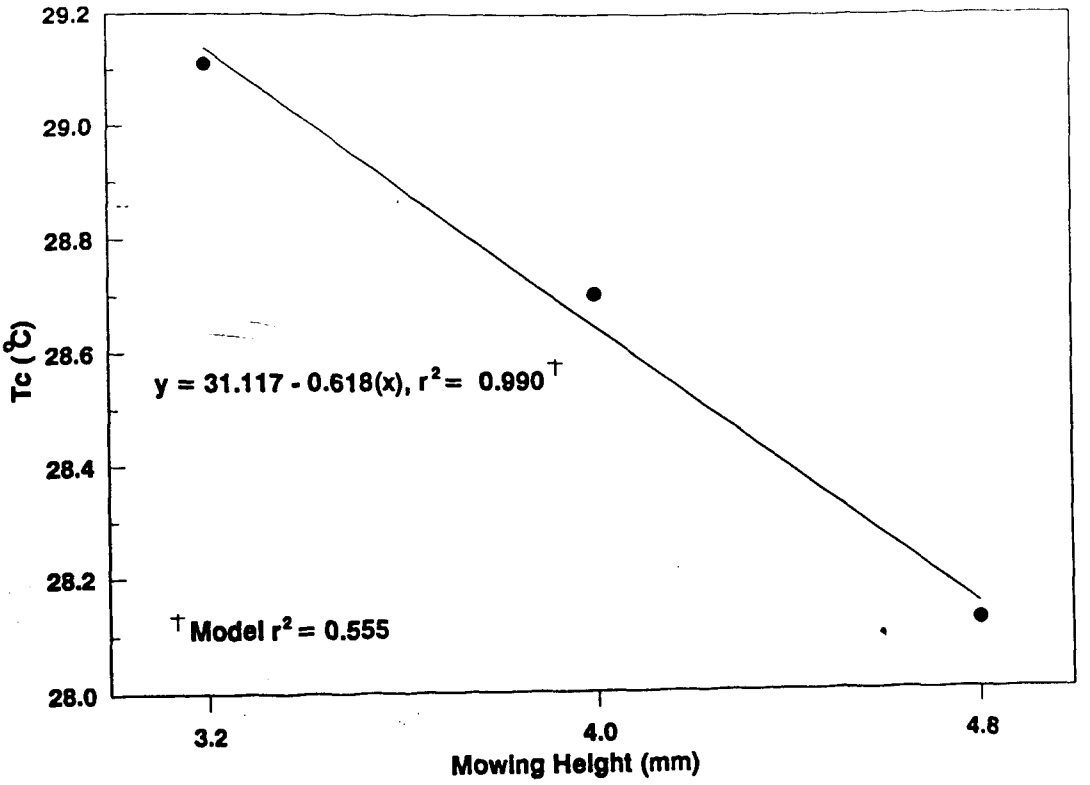



Figure 16. Creeping bentgrass canopy temperatures (Tc) as a function of mowing height, measured 16 June 1989.

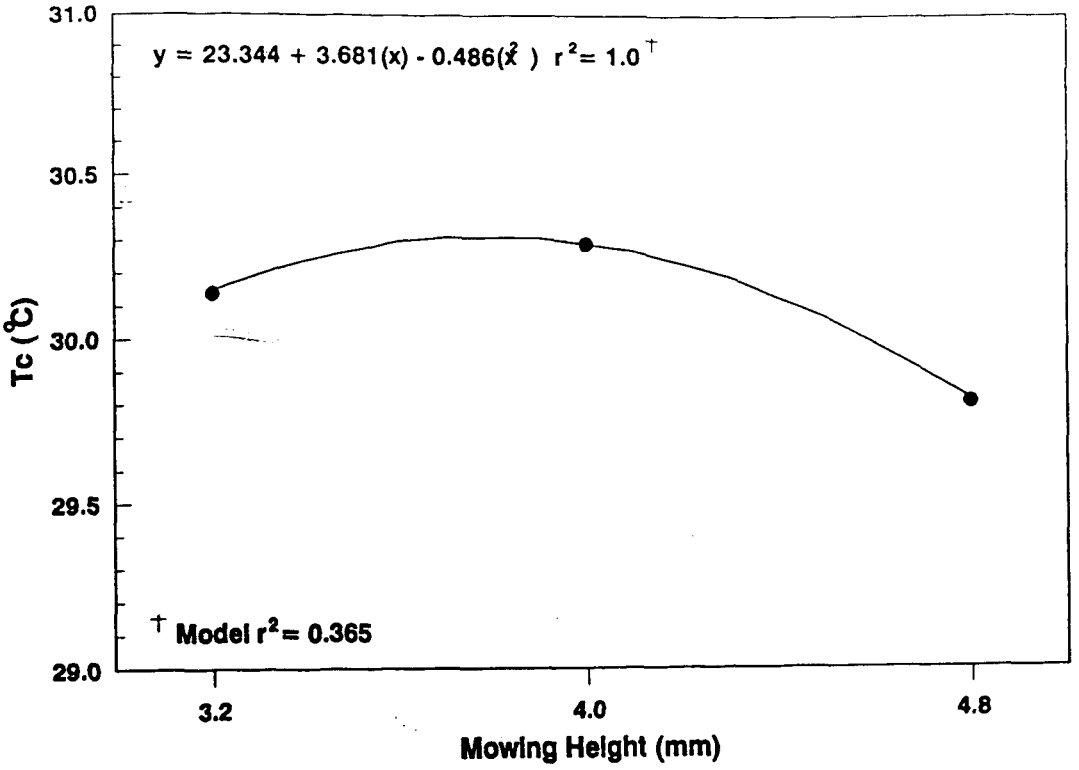



Figure 17. Creeping bentgrass canopy temperature (Tc) as a function of mowing height, measured 11 June 1990.

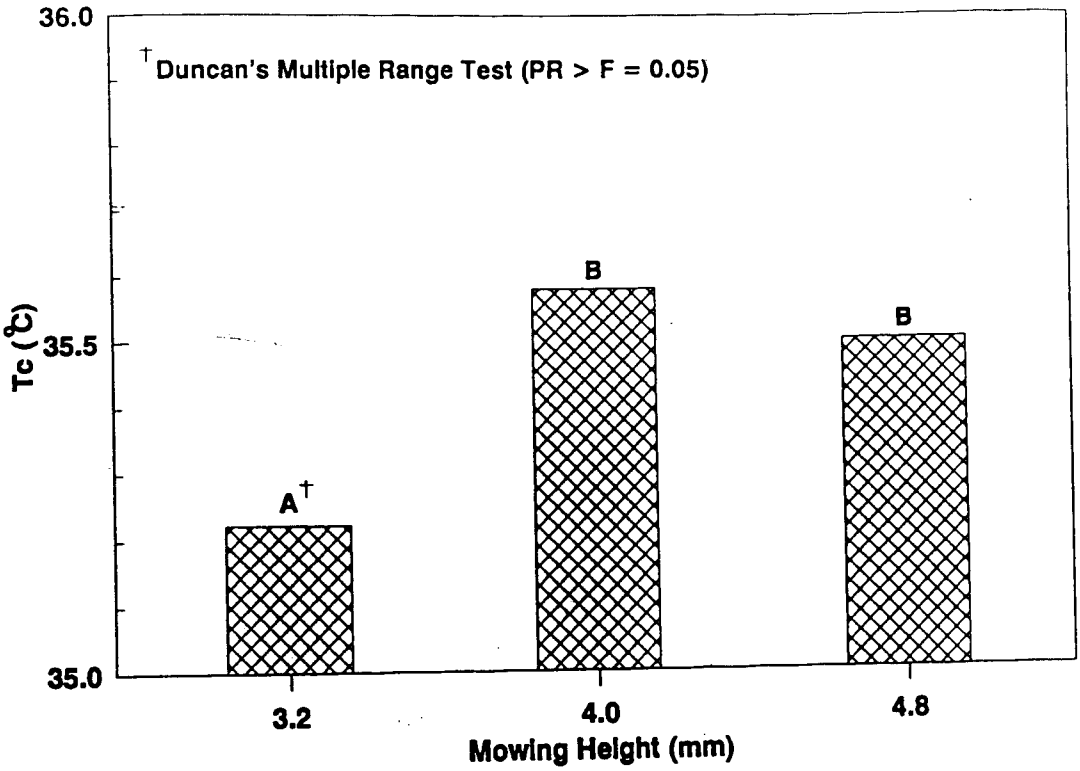



Figure 18. Mowing height effects on creeping bentgrass canopy temperatures (Tc) measured 28 June 1989.

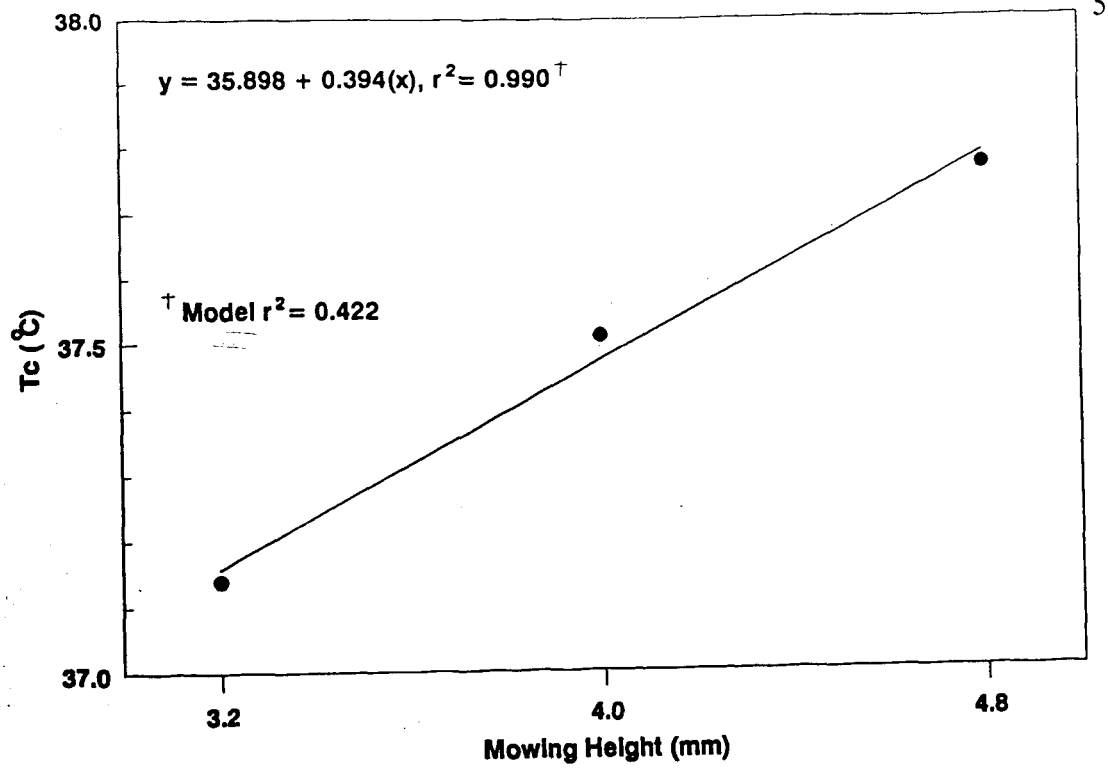



Figure 19. Creeping bentgrass canopy temperature (Tc) as a function of mowing height, measured 25 June 1990.

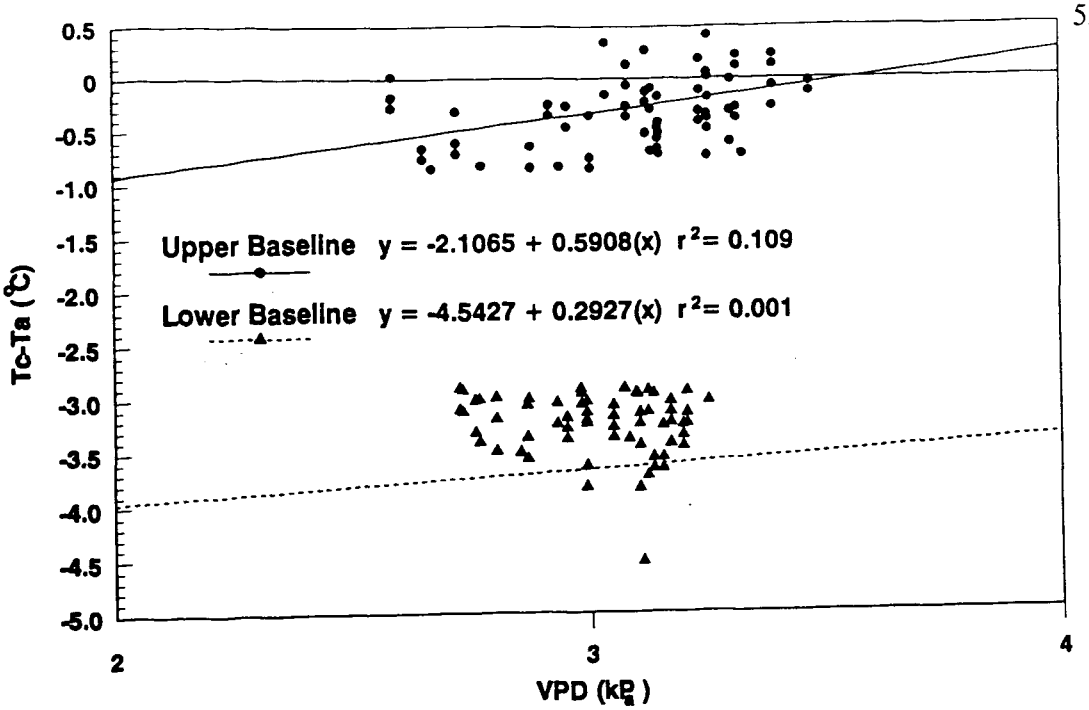
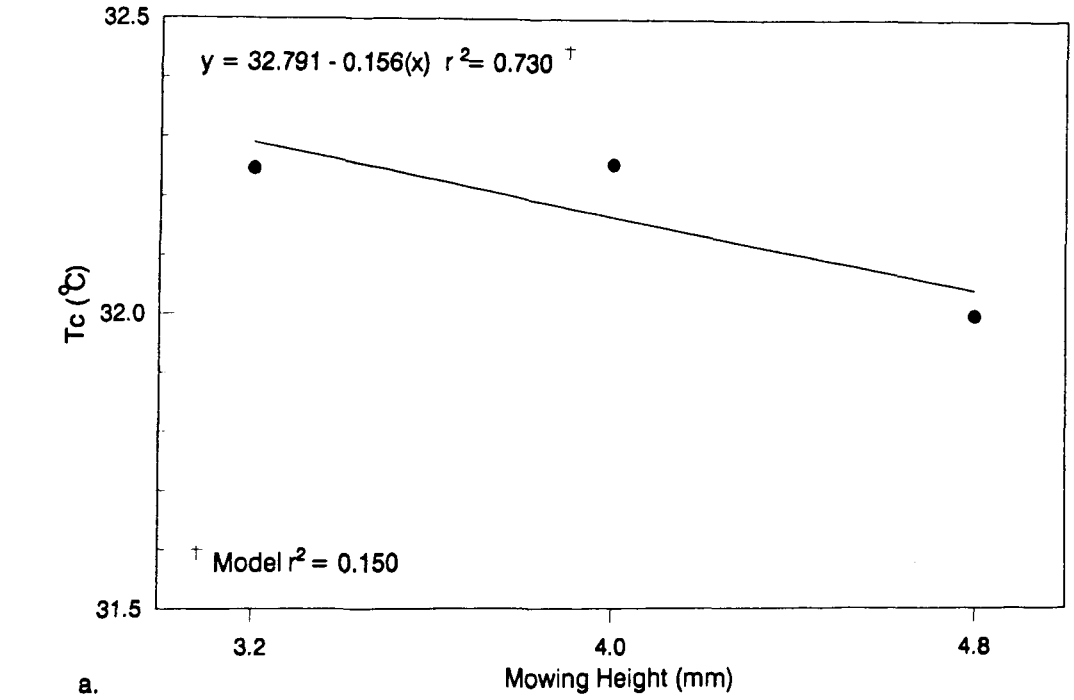



Figure 20. Canopy-air temperature differences (Tc-Ta) as a function of vapor pressure deficit (VPD) baselines for creeping bentgrass, determined using upper and lower 25% of Tc-Ta values measured 3, 5, and 9 September 1990.



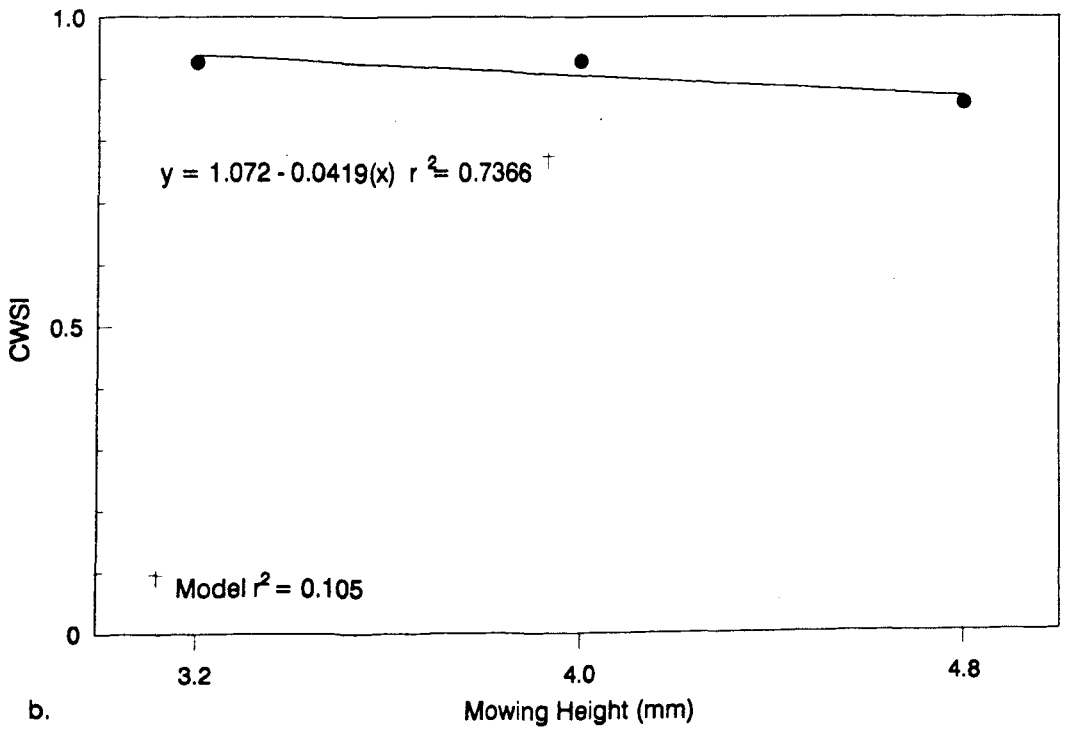




Figure 21. Linear function of a) canopy temperature and b) Crop Water Stress Index values (CWSI) versus mowing height, measured on a creeping bentgrass green, measured on 9 September 1990.