4.5 INTERPRETING SOIL QUALITY: SPIDER RADAR GRAPHS FOR MULTIPLE INDICATORS

As discussed in chapter 2 and 3, spider/radar graphs give users a composite environmental quality evaluation by showing how well multiple indices conform to the limits of each indicator's sustainable range (as compared to scanning through many control charts).

Data from the last sampling (October 2001) have been taken from the control charts and converted to spider/radar graphs (Figures 4.27 to 4.33). In order to standardize all of the soil quality indictors from control charts and graphs to spider/radar graphs discretionary upper and lower threshold limits were chosen for five indicators. The soil indicators that had no previous established limits are; total C and N, mineralizable C and N, and aggregate stability. The organization of the spider/radar graphs is presented below.

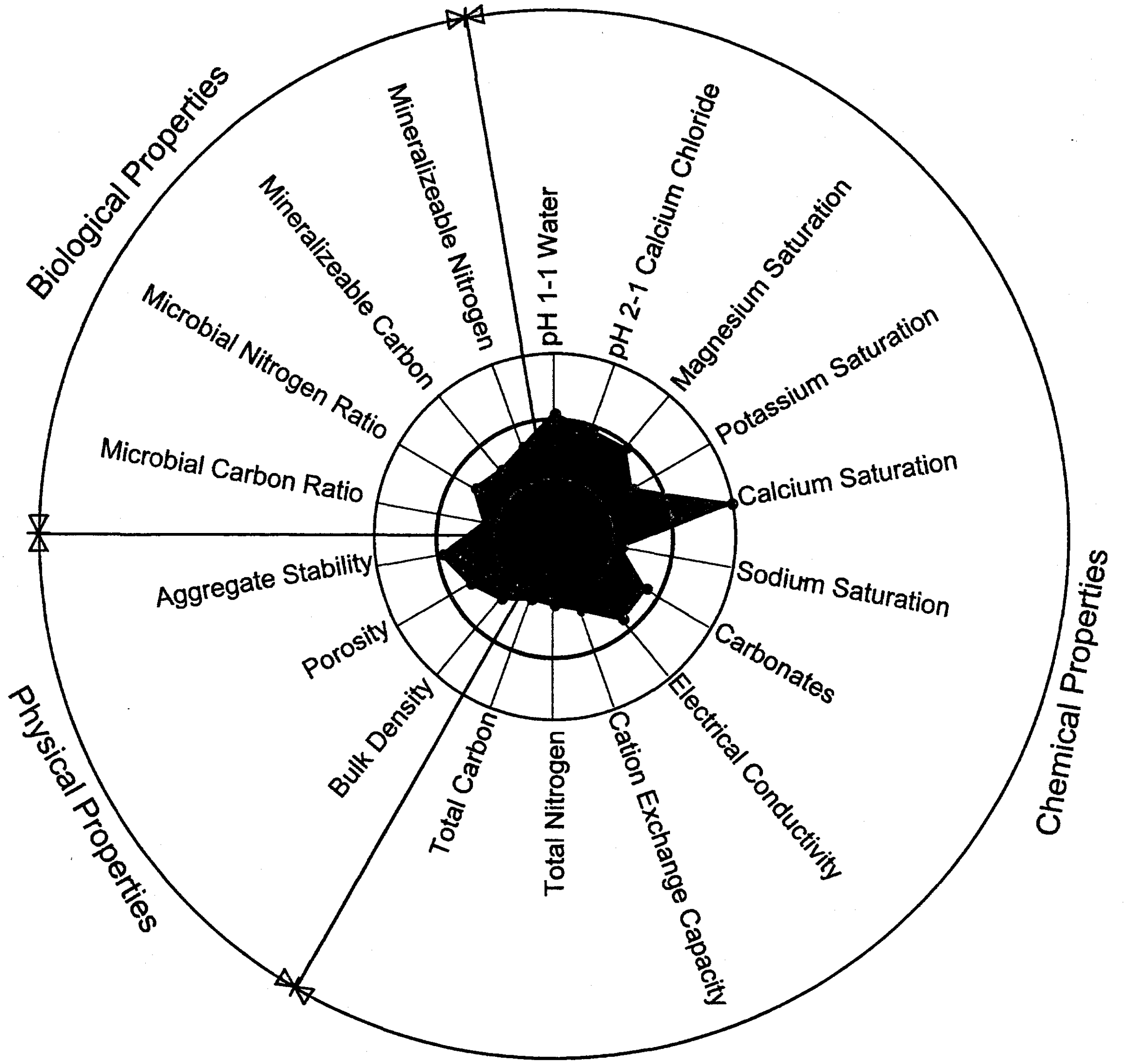

Figure 4.27. Composite soil quality index for eighteen soil quality indicators on the 10th fairway (CH-10) measured on October 8th, 2001. The standardized value for calcium saturation is shown as 2x the upper control limit. The actual value is 2.02x the upper threshold limit.

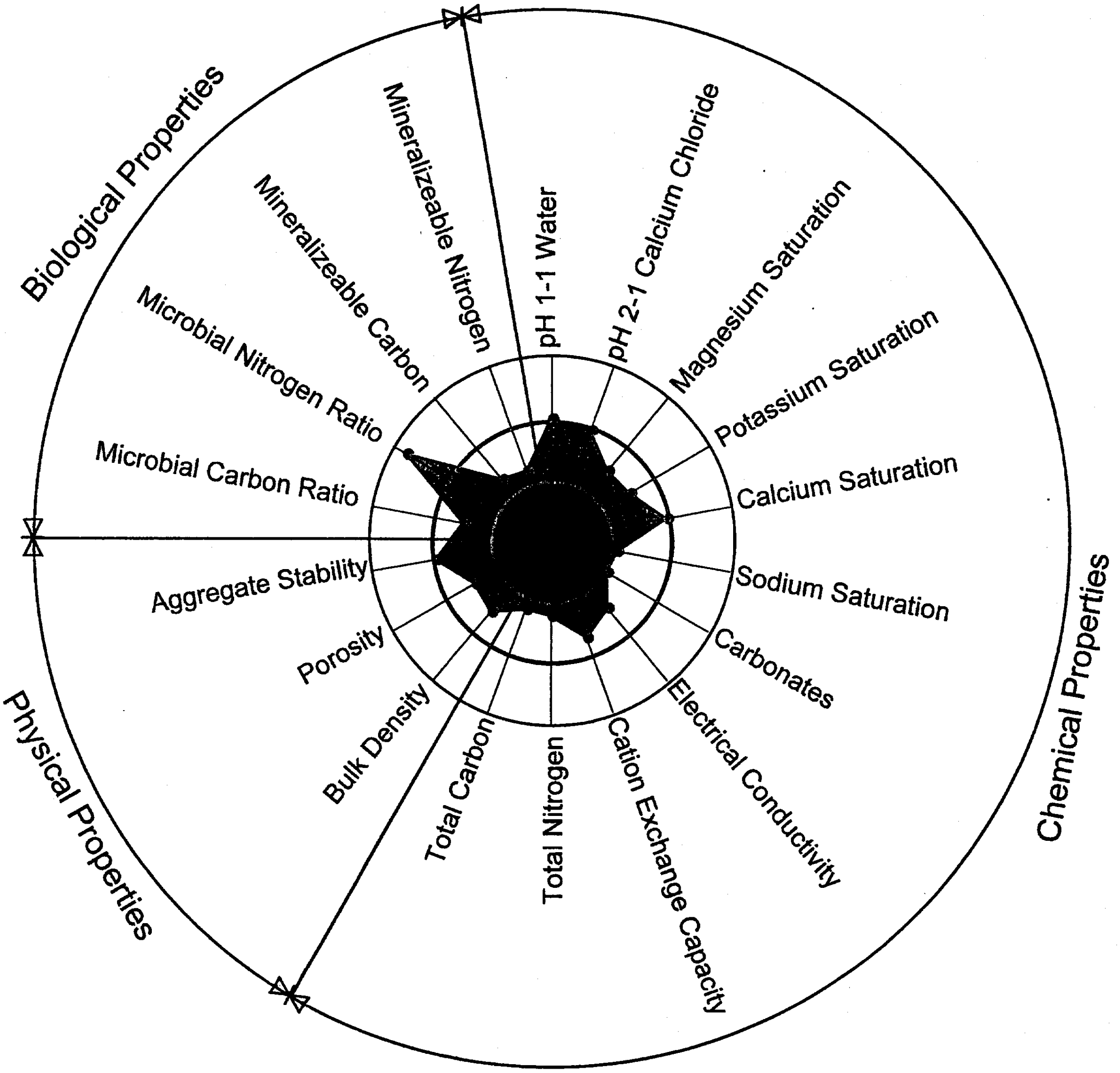

Figure 4.28. Composite soil quality index for eighteen soil quality indicators in the middle of the 12th fairway (CH-12F) measured on October 8th, 2001.

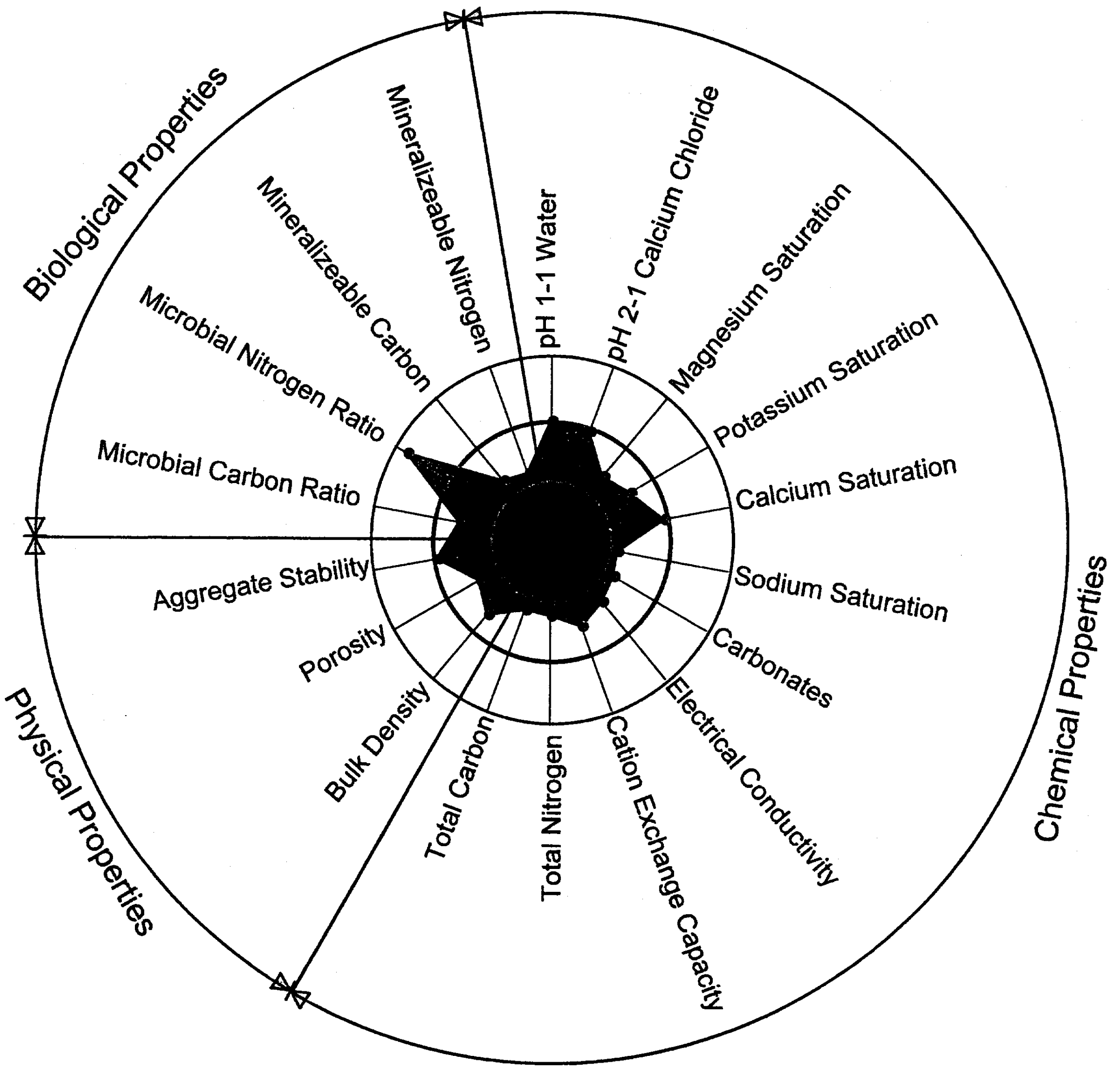

Figure 4.29. Composite soil quality index for eighteen soil quality indicators near the tee-box of the 12th fairway (CH-12T) measured on October 8th, 2001.

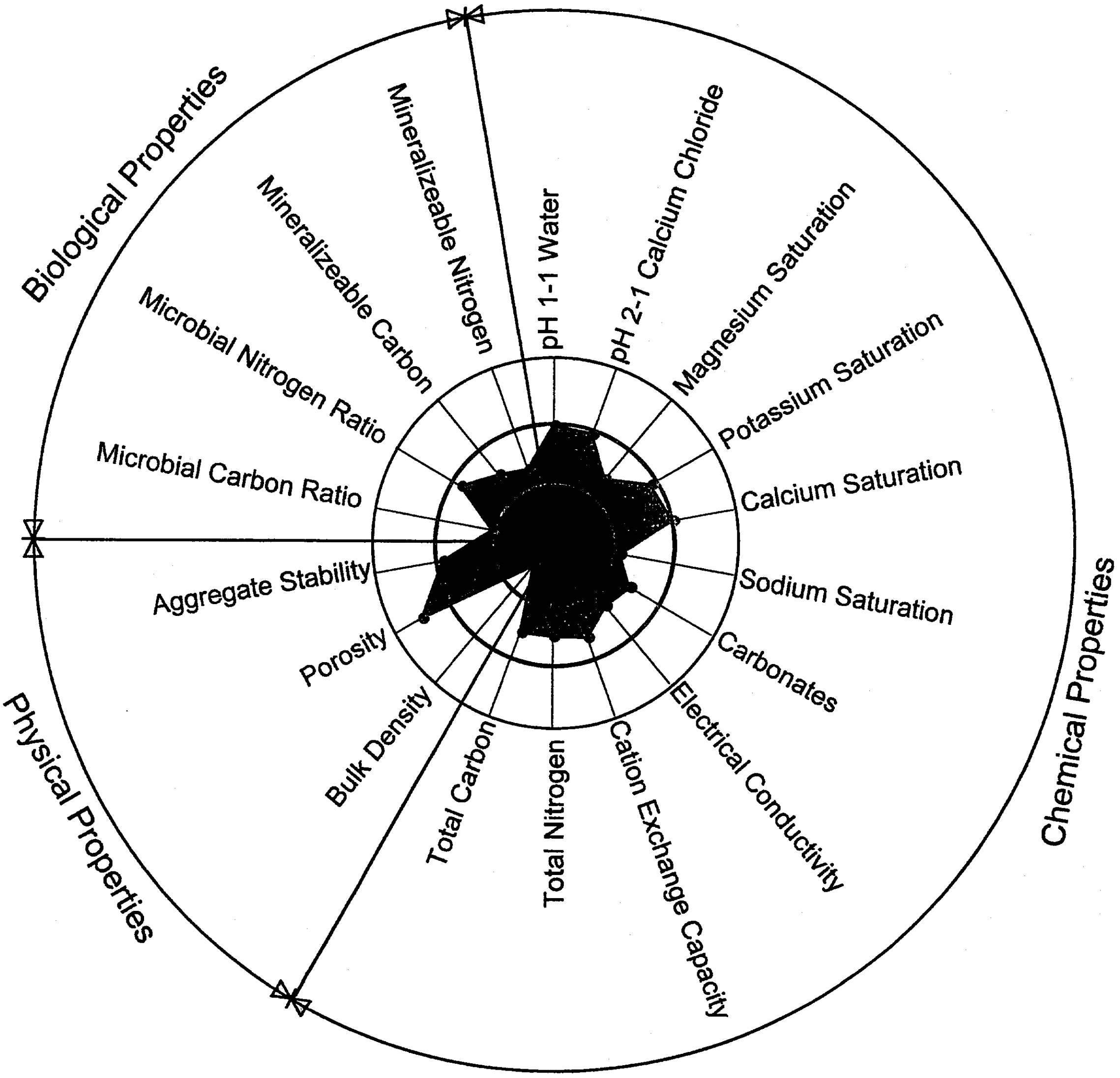

Figure 4.30. Composite soil quality index for eighteen soil quality indicators on the 13th fairway (CH-13) measured on October 8th, 2001.

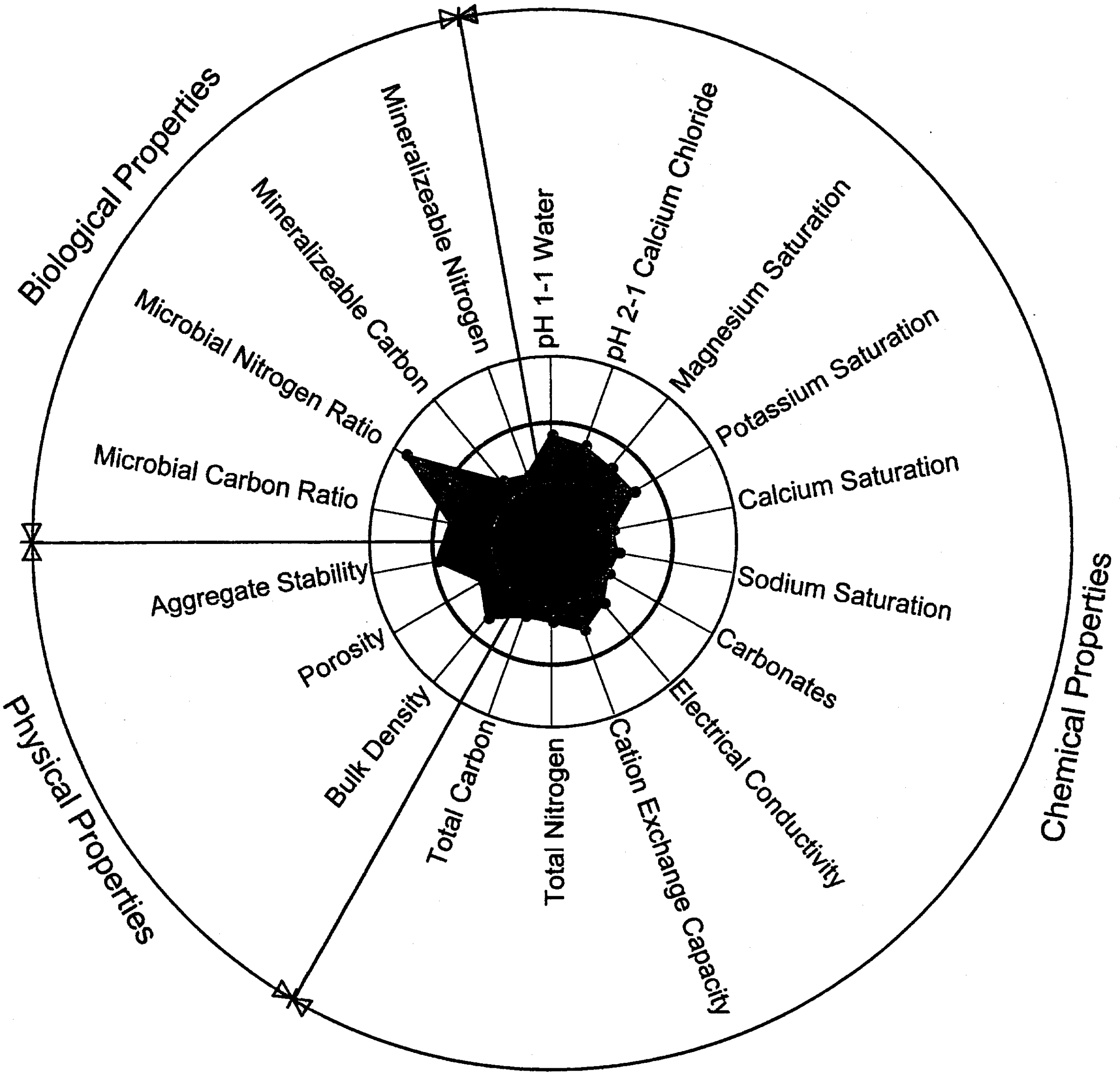

Figure 4.31. Composite soil quality index for eighteen soil quality indicators on the 14th fairway (CH-14) measured on October 8th, 2001.

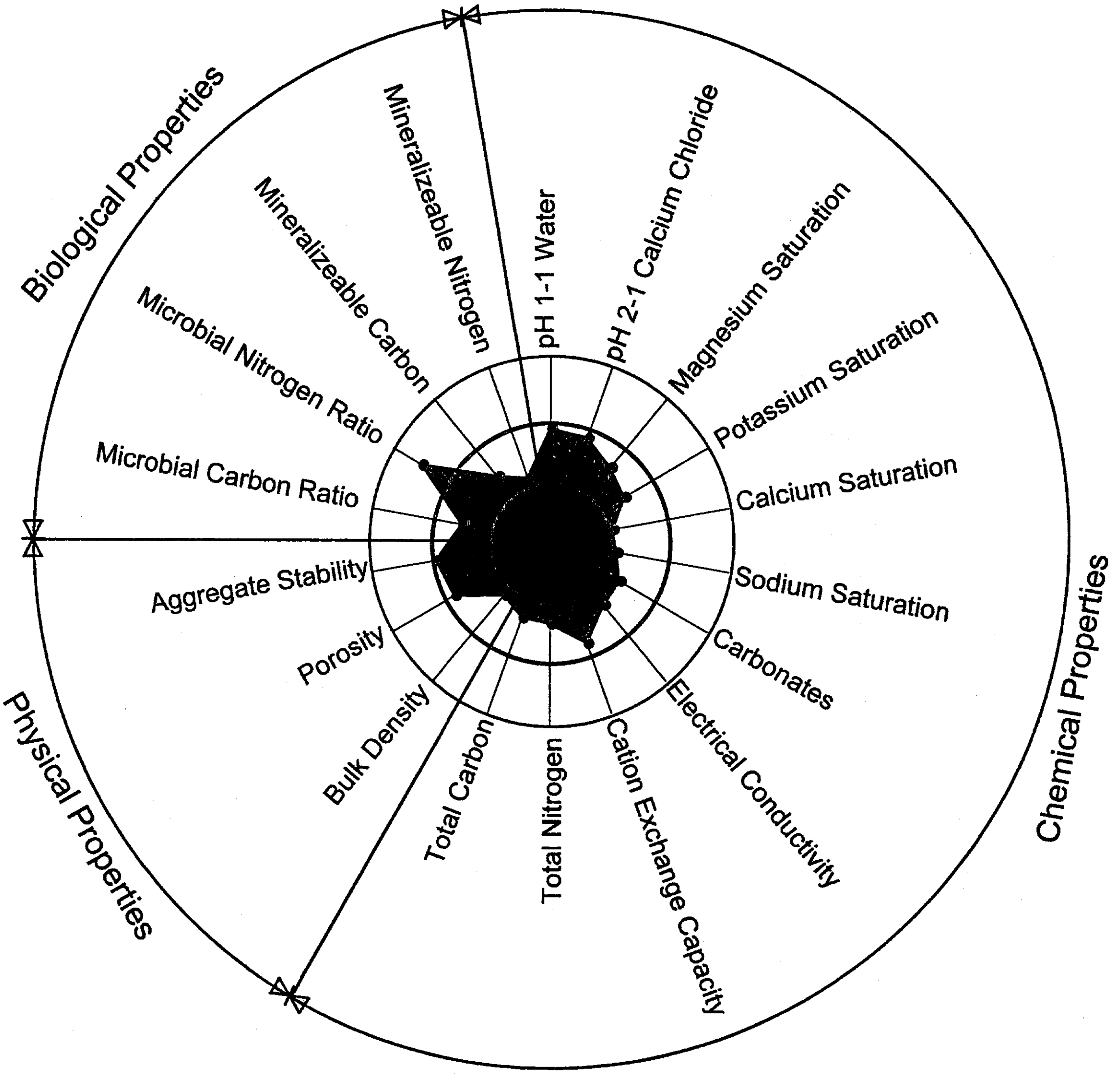

Figure 4.32. Composite soil quality index for eighteen soil quality indicators on the 15th fairway (CH-15) measured on October 8th, 2001.

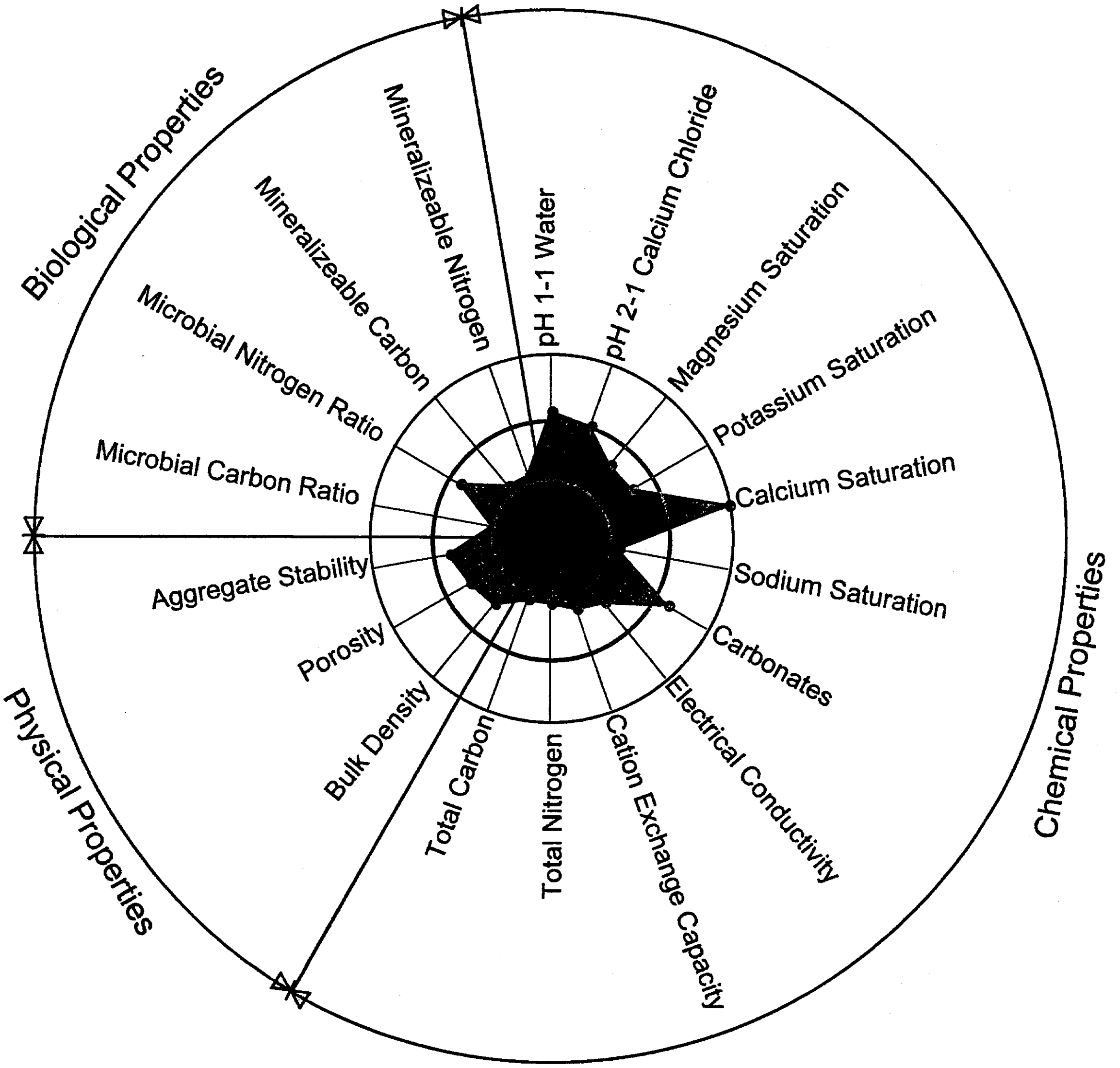

Figure 4.33. Composite soil quality index for eighteen soil quality indicators on the 18th fairway (CH-18). The standardized value for calcium saturation is shown as 2x the upper control limit. The actual value is 2.97x the upper threshold limit measured on October 8th, 2001.

The spider/radar graphs previous presented have shown the status of multiple soil quality indicators at one sampling or time period. The use of spider/radar graphs to reflect the status of soil quality can also be used to identify trends or changes in soil quality over time. Golf course superintendents may find it useful to track soil or environmental indicators frequently such as monthly or every 3 to 6 months. Frequent sampling and analysis allows for identification of potential problems before they reach levels above or below the control limits. The 10th fairway, as previously discussed, contained high amounts of free $CaCO_3$ and had pH and calcium saturation values near or exceeding the upper control limit (Figure 4.27). However, the data collected and graphed since October 1999 shows a high amount of calcium and pH levels near the upper control limit from May 2000 to October 2001 (Figures 4.34 through 4.38).

	Figure	**Site and Date**	**Page**
1.	Figure 4.34 –	October 1999, CH-10	Page 232
2.	Figure 4.35 –	May 2000, CH-10	Page 233
3.	Figure 4.36 –	October 2000, CH-10	Page 234
4.	Figure 4.37 –	May 2001, CH-10	Page 235
5.	Figure 4.38 –	October 2001, CH-10	Page 236

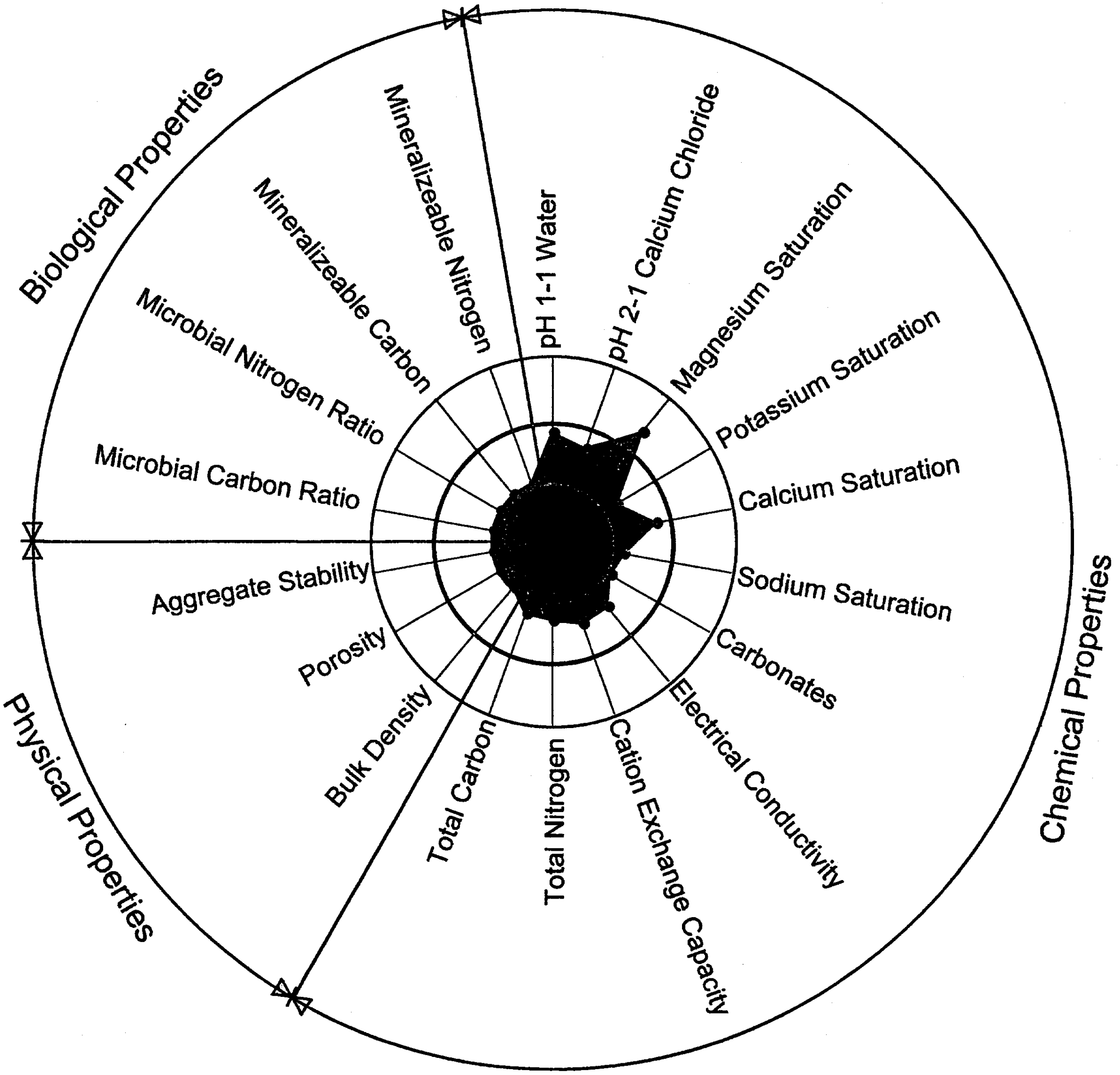

Figure 4.34. Composite soil quality index for eight-teen soil quality indicators on the 10th fairway (CH-10) measured in October 1999.

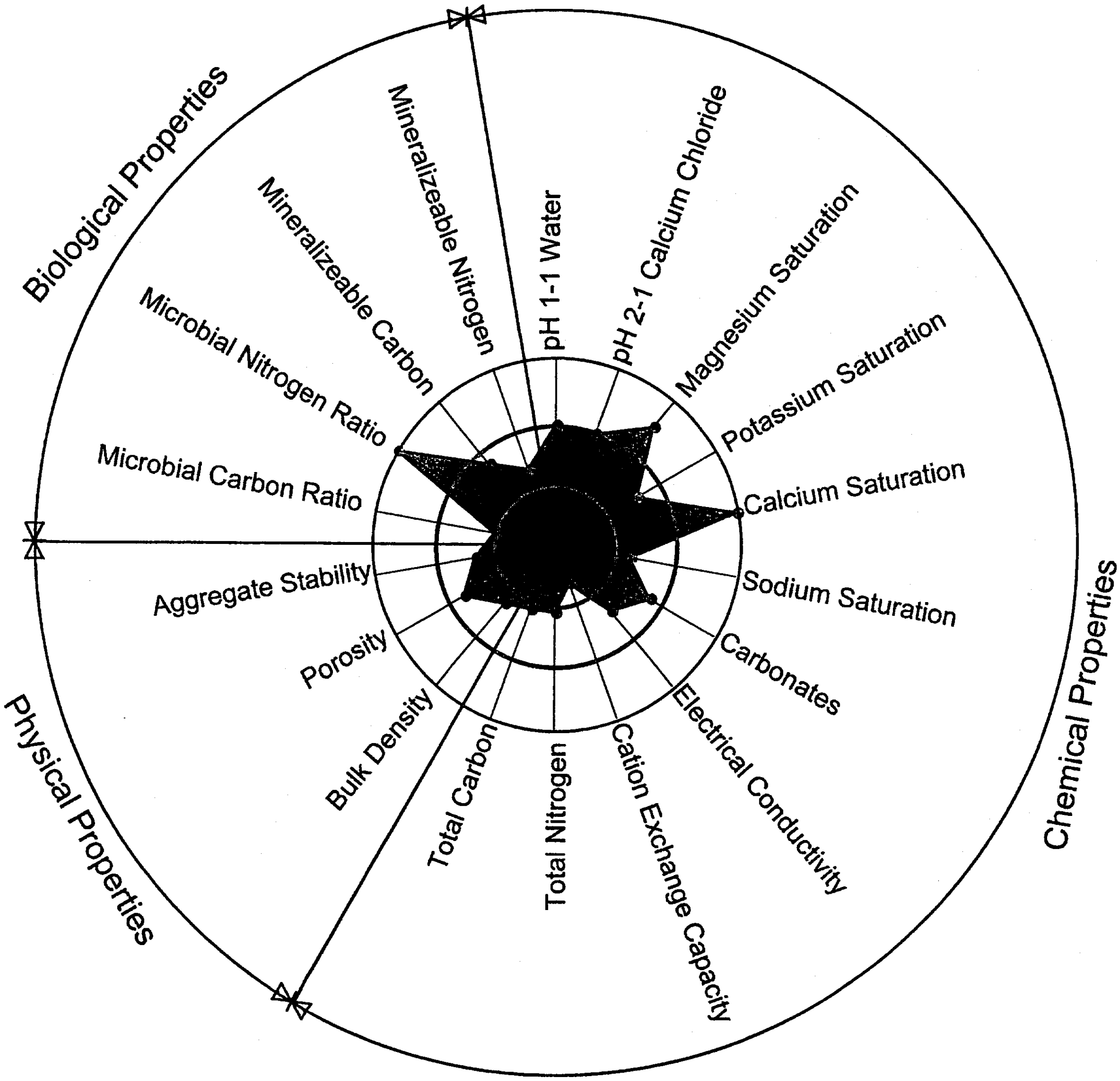

Figure 4.35. Composite soil quality index for eighteen soil quality indicators on the 10th fairway (CH-10) measured in May 2000. The standardized values for calcium saturation and microbial biomass nitrogen ratio are shown as 2x the upper control limit. The actual values are 3.97x and 2.58x respectively.

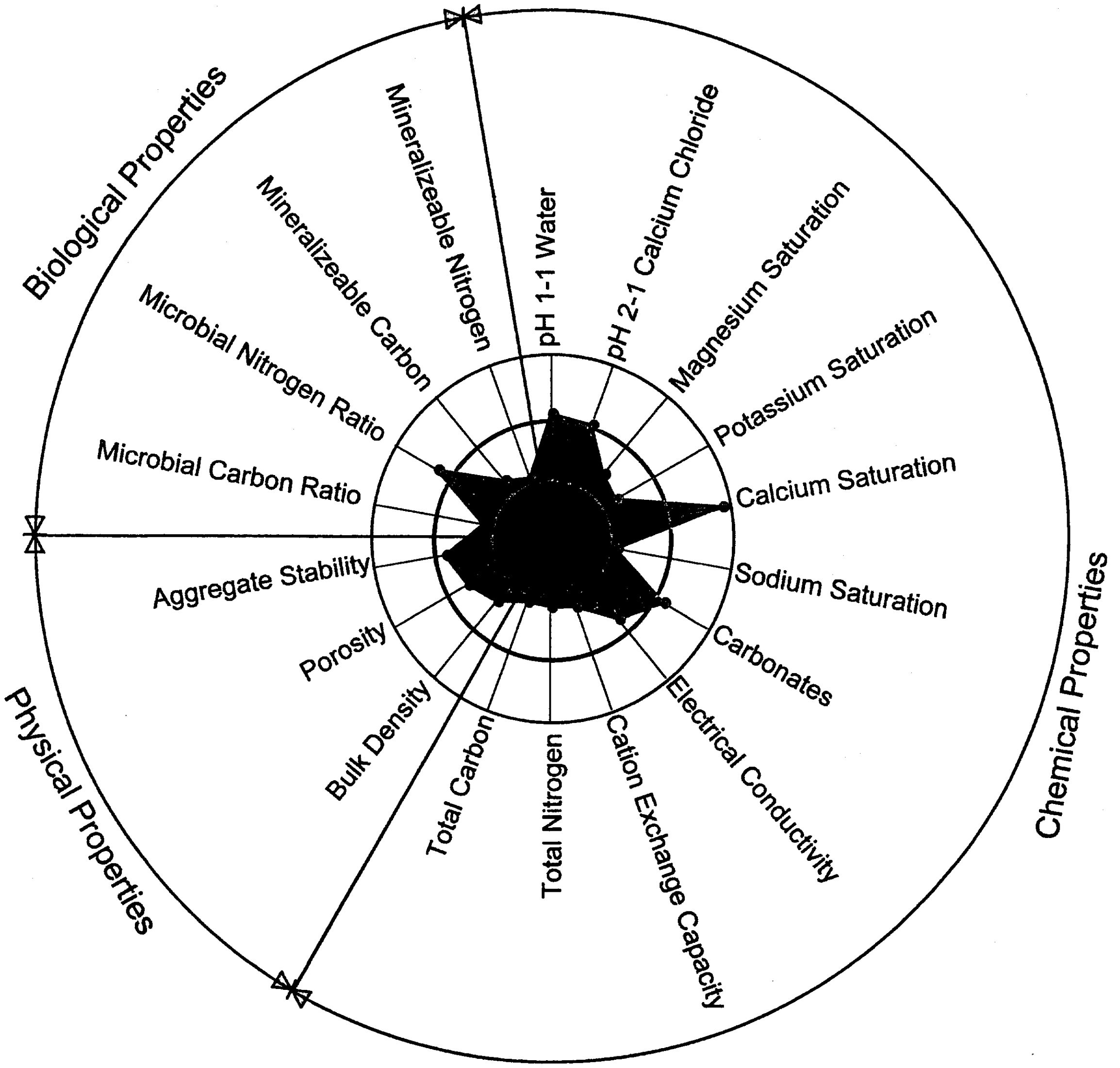

Figure 4.36. Composite soil quality index for eight-teen soil quality indicators on the 10th fairway (CH-10) measured in October 2000.

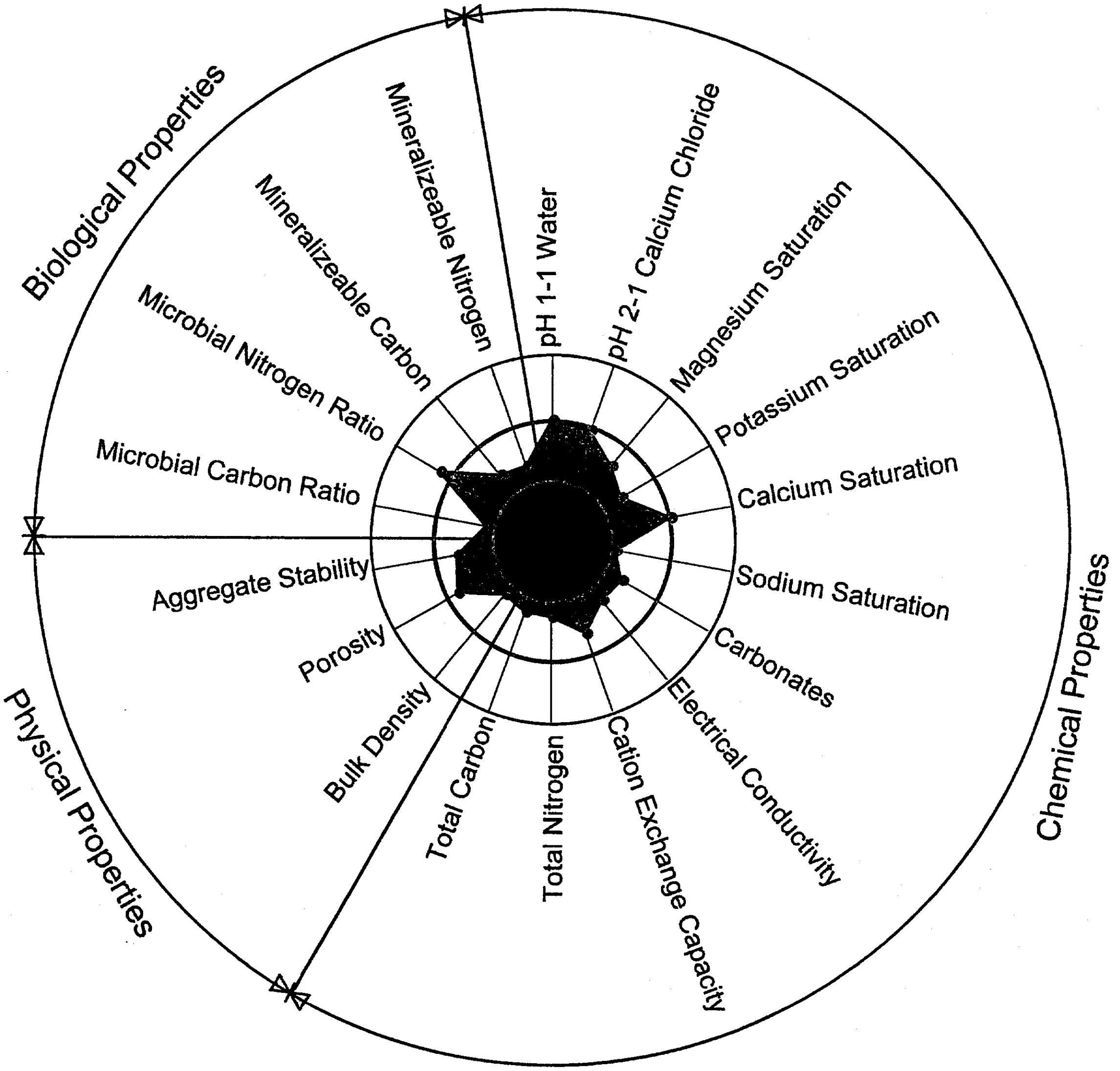

Figure 4.37. Composite soil quality index for eight-teen soil quality indicators on the 10th fairway (CH-10) measured in May 2001.

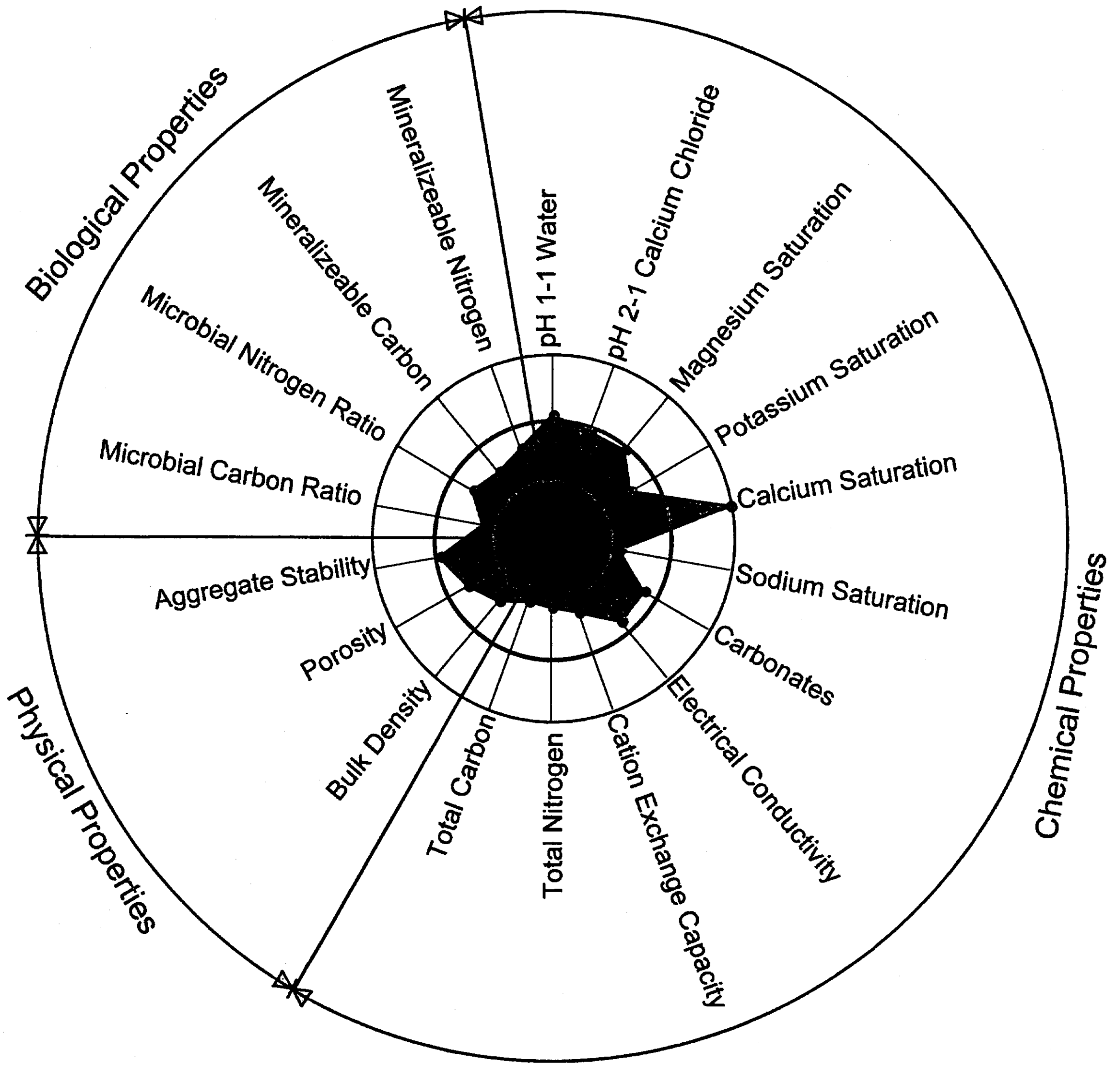

Figure 4.38. Composite soil quality index for eight-teen soil quality indicators on the 10th fairway (CH-10) measured in October 2001. The standardized value for calcium saturation is shown as 2x the upper control limit. The actual value is 2.03x the upper control limit.

4.6 CONCLUSION

The overlying goal of this project was to monitor numerous soil quality parameters during and after the construction of a golf course. Soil quality was quantified and evaluated using a comprehensive soil quality index that involved multiple indicators. These indicators can be grouped into three areas; physical, biological, and chemical soil properties.

Physical Soil Properties

Physical properties were monitored by measuring bulk density, porosity, and aggregate stability. Bulk density and porosity are inversely related to each other, an increase in one causes a decrease in the other property. Throughout the study, bulk density and porosity remained within allowable limits except for the 13th fairway. These bulk density of these soils were fairly low and were similar to the undisturbed soil conditions. Soils with excessively low bulk densities (and high porosities) are sensitive to compaction, especially under moist conditions. Aggregate stability improved over the last two years since construction was complete. The establishment of Zoysiagrass after the October 1999 sampling date may have been the contributing factor.

Chemical Soil Properties

Chemical properties were monitored by measuring cation saturation, total C and N, soluble salts and soil pH. Soil pH, Ca saturation, and free $CaCO_3$ was high and near the upper control limit on the 10th and 18th fairway. While Ca toxicity usually isn't a problem on turf soils, high amounts of Ca could lead to K, Mg, and micronutrient deficiency. Potassium and Mg were also measured and were found to be within the control limits. The source of the Ca could be from the limestone base layer used in construction or from salts present in the irrigation water. Water testing and continued soil testing on the 10th and 18th fairway may be appropriate to monitor this situation. Electrical conductivity (soluble salts) was within the control limits, however, compared to the undisturbed soils the salt content on the golf course soils increased. This is probably due to the use of irrigation water containing soluble salts.

Biological Soil Properties

Biological properties measured included microbial biomass C and N, mineralizable C and N, and potential mineralizable C and N. Overall, compared to either the pre-construction soil conditions (1997-1998) or the undisturbed soil conditions (July 2000) there was a general decrease in biological soil quality of the fairway soils. Both total C and N were lower compared to both the undisturbed and pre-construction conditions. Potential mineralizable C and N were lower than the undisturbed soil conditions but similar to values measured before construction. Microbial biomass C was lower than the pre-construction soil conditions however they were similar to those of the undisturbed soil. Microbial biomass N was lower than both the soils sampled before construction and those of the undisturbed grassland sampled in July 2000. Continued monitoring of these properties will provide more information on the resilience and stability of the soil's microbial community to disturbance from golf course construction and management.

It is difficult to assess the exact impact on indicators of soil quality from golf course construction since the seven soils measured before construction and those located in the undisturbed areas are now completely different than those on the golf course fairways. While it may not be reasonable to hope that the conditions of these soils will someday return to the native conditions, this study did identify several soil quality indicators that underwent considerable change as a result of golf course construction. The use of a multiple index, using spider/radar graphs and control charts, identified changes to aggregate stability, calcium saturation, soil pH, and numerous biological soil properties that at times were outside the established control limits. Golf course superintendents should be aware of the negative impact construction has on the biological properties of soil such as microbial biomass C and N and mineralizable C and N. Adjustments to management practices immediately after construction could help facilitate an improvement in these properties. Soil tests conducted during the establishment of turf or shortly after the course has begun operation may help identify or prevent problems with chemical and physical soil properties.

Managing the soil or environmental quality of an ecosystem requires the consideration of a broad range of environmental quality indicators. The production of an evaluation program which is customized based on the function of an specific ecosystem (this case soil) can establish whether environmental processes are operating within a sustainable range. Presenting multiple soil quality indicators on a standardized spider/radar graph has potential to provide golf course managers with a composite visual representation of environmental quality. The potential to link these evaluation charts to remedial management databases can provide addition tools to golf course superintendents or land managers toward the establishment of a sustainable ecosystem .

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