The Impact of Golf Courses on Soil Quality

Executive Summary to USGA, November 2, 1998

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This project is monitoring some soil quality criteria needed to assess the long-term impact and sustainability of golf courses on the environment. The research was initiated on a native grassland destined to become Colbert Hills Golf Course, near Kansas State University in Manhattan, Kansas. Colbert Hills has been designated as a "living laboratory" by KSU to highlight its utility for research in environmental resources and turf management. This situation presents a unique opportunity to characterize site resources prior to construction and follow the long-term impacts and changes brought on by construction, use, and management of the facility. The golf industry needs this information to realistically understand its environmental impact, to formulate knowledgeable responses to public inquiries, to establish management strategies for new courses, and to provide knowledge for future planning and growth.

Relevance of Soil Quality to Golf Courses

Golf courses are only as sustainable as their weakest natural component, which can often be soil quality. The inherent sustainability of managed areas can be viewed as inversely proportional to the level of management needed to maintain it. Golf courses that diverge the most from their natural surroundings require the highest levels of management inputs to remain sustainable.

Soils plays a central role in determining the sustainable land use potential of golf courses. Soil influences such critical properties as; leaching, aeration, fertility, water relations, rooting, microbiological activity, and chemical use, detoxification, and effectiveness. A carefully selected set of properties, matched to the intended use of the soil, can be monitored as indicators of soil quality change. As these soil quality indicators degrade, they become the primary factors preventing superintendents from achieving course conditions expected by their management and players. The influence of siting, constructing, developing, and using a golf course on these indicators will ultimately determine both the sustainability of a course and the level of management necessary for day-to-day operations. This project is initiating a process of tracking changes to soil quality indicators during the life of a golf course.

To evaluate the relative sustainability of different soils, soil scientists use indicators of soil quality. Selection of soil quality indicators should be related to soil use but reliable indicators for golf course soils have not yet been studied. This study will extend the concept of soil quality by identifying those indicators specifically important to the construction and sustainable use of a golf course.

1998 Research

Construction on Colbert Hills began in May, 1998. Prior to construction, we made field observations and collected soil samples to establish base-line values for critical indicators of soil quality.

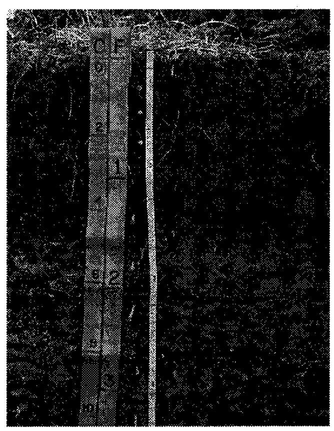
Starting in the spring and summer of 1997, soil scientists from Kansas State University and the USDA Natural Resources Conservation Service (NRCS) identified and mapped nine soil series on the site. By combining soil maps and architectural drawings of the course, we have located soil types according to their fairway and rough locations. Two sites for each soil type were selected and marked by global positioning for future referencing. One site was located in a fairway and one in an adjacent rough. The fairway site will be subject to the expected disturbances accompanying course construction. The site in the rough will be undisturbed.

For each soil type identified, a pit was dug and the soil profile was fully characterized according to NRCS field standards. Loose samples for further analysis were collected from each horizon down to bedrock or to a depth of at least 2 meters.

Sampling and Analyses Began and/or Completed

- Soil map of Colbert Hills
  A soil map has been nearly completed at a scale = 1:7920 (8 inches per mile). At this scale the map is 4 times more detailed than maps typically found in soil survey reports.
- Soil characterization
  Open pit identification of horizonation, depth, texture, color, structure, consistency, and pore and root distribution as per the USDA-NRCS Soil Survey Investigations Report No. 42, Version 3.0, Soil Survey Methods Laboratory Manual (1996).
- Soil series identification
  Surface texture, slope, depth, drainage, permeability, physiographic location, and parent material.
- Soil sample collection and and laboratory anlysis.
  Operations performed using standard methodology as published in the American Society of Agronomy Monograph No. 9, Methods of Soil Analysis (1965)
  For each horizon present we have determined: depth, bulk density, pH, (1:1 water), pH (2:1 $CaCl_2$), total nitrogen (%), total carbon (%), microbial biomass nitrogen (ug g^{-1}), microbial biomass carbon (ug g^{-1}).

Dr. Michel Ransom (KSU) and Bill Wehmueller (NRCS) taking soil probes to identify the soil types on the native grassland site that is to become Colbert Hills Golf Course near Manhattan, Kansas.



One of the soils located on the Colbert Hills site is the Konza silt loam. These soils are found on 1 to 3 percent slopes on nearly level to gently sloping summits of benches. They are deep, moderately well drained, slowly permeable soils formed in loess over hillside sediment over residuum weathered from cherty limestone.

The Impact of Golf Courses on Soil Quality

Annual Report to USGA, November 2, 1998

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It is unlikely that the funding level approved for this project will allow for both a complete set of sample collection and sample analysis over its 5-year span. We believe that it is most critical to place the highest priority on an annual sample collection and archive those samples that cannot be analyzed. This would allow some future funding source to support a complete analysis and would obviate a missed opportunity for gathering information necessary to fully describe the flux in soil quality indicators over their most transitory period.

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  For each horizon present we have determined:

  depth

  bulk density

  pH (1:1 water)

  pH (2:1 $CaCl_2$)

  total nitrogen, %

  total carbon, %
- Biological Indicators

  total nitrogen (g kg^{-1})

  total carbon (g kg^{-1})

  microbial biomass nitrogen (ug g^{-1})

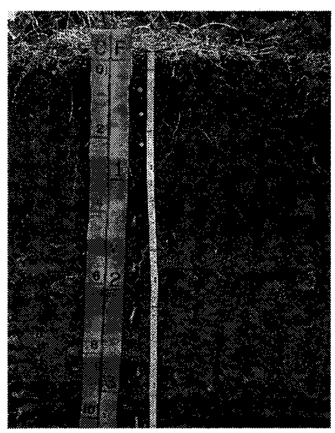
  microbial biomass carbon (ug g^{-1})

Research to be Initiated during 1999.

As of this writing, 16 holes on the golf course have been graded to final shape but will not receive their topsoil cover until the Spring of 1999. When the final layer of soil has been added, but prior to sodding or seeding, additional soil sampling will occur. Some criteria will be established on disturbed areas to describe the extent of soil removal or addition that has been necessary. Sampling sites will be the same as previous locations, as indicated by GPS referencing. Samples will be collected using cores instead of open pits to minimize disturbance.

Additional laboratory analyses on samples collected earlier will continue. These analyses, added to the open-pit evaluations, will establish the base-line values necessary to reference soil quality changes. Analyses yet to be completed would include; cation exchange capacity, calcium carbonate equivalency, base saturation (calcium, magnesium, potassium, and sodium saturation), organic carbon content, bulk density, porosity, microbial biomass, and microbial activity. In addition, as suggested by the USGA review in September, aggregate stability and possibly infiltration will be added to the list of analyses.

Dr. Michel Ransom (KSU) and Bill Wehmueller (NRCS) taking soil probes to identify the soil types on the native grassland site that is to become Colbert Hills Golf Course near Manhattan, Kansas.



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Soil Characterization Data

Soil Mapping and Soil Characterization
Status Report for the Colbert Hills Golf Course Project
August 14, 1997

Introduction

Part of the intended use of the Colbert Hills Golf Course is to serve as a living laboratory for research. The Colbert Hills Golf Course will be constructed on a site that is currently used for native rangeland. Although the site has been modified from its natural condition by grazing, human activity has largely left the soils, water, and native flora and fauna undisturbed. This presents a unique opportunity to do a site resource characterization prior to construction of the facility. Moreover, the environmental impact of constructing a golf course can be studied and the long-term effects on the environment of using and managing a golf course can be investigated over time. As part of the site resource characterization, we plan to assess the soil resources by identifying soils and determining soil properties such as texture, depth, permeability, infiltration rates, organic carbon content, pH, plant nutrient availability, etc.

Objectives

1. Work with USDA-NRCS to conduct an evaluation of soils information for the site using the Riley County Soil Survey (Jantz et al., 1975), which was made at a scale of 1:24,000. Determine if the existing scale shows sufficient detail. If the existing soil survey is satisfactory, digitized soil survey information is already available. If a larger scale map is needed, work with USDA-NRCS to make a new soil survey, probably at a scale of 1:12,000. This map would then need to be digitized.

2. Select and sample about 10 representative soils for detailed soil characterization analyses.

3. Conduct soil characterization analyses for each horizon of each site. Analyses will include particle size distribution (% sand, silt, and clay); pH; organic C; extractable Ca, Mg, K, and Na; and electrical conductivity.

4. Conduct soil characterization analyses for surface horizon samples of an additional 10 sites per soil.

Status as of 14 August 1997

Objective 1: In progress

USDA-NRCS was contacted to obtain an evaluation of the existing soil survey information for the site. William E. Wehmueller, Area 3 Soil Scientist with USDA-NRCS, determined that the existing soil survey made at a scale of 1:24,000 is not detailed enough for the purposes of this project. Therefore, NRCS is currently making an updated survey at a scale of 1:12,000 and developing a new mapping legend. This survey is approximately 50% complete.

Objective 2: Complete

Nine sites representing typical landscape positions were sampled for detailed laboratory analysis. The sites selected were located in a fairway on in an adjacent rough. Each site was accurately marked for future reference using global positioning equipment. A 1 x 2-m pit was dug with a backhoe at each site to bedrock or to a depth of at least 2 m. A detailed description of the soil morphology (Attachment A) was obtained for each site using the procedure of the Soil Survey Staff (1993). Bulk samples were collected near the center of each horizon for laboratory analysis.

Objective 3: In progress

The samples will be analyzed using the procedures of the Soil Survey Laboratory Staff (1996). Undisturbed samples were also collected from selected horizons for bulk density and soil micromorphological examination using thin sections and a petrographic microscope. A listing of the samples collected and preliminary laboratory data for pH, total nitrogen, and total carbon are given in Table 1.

Objective 4: Not started

References Cited

Jantz, D.R., R.F. Harner, H.T. Rowland, and D.A. Gier. 1975. Soil survey of Riley County and part of Geary County, Kansas. USDA Soil Conservation Service, Washington, DC.

Soil Survey Laboratory Staff. 1996. Soil survey laboratory methods manual. Soil Surv. Invest. Rep. No. 42, ver. 3. USDA Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE.

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Submitted By

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SOIL SURVEY LEGEND FOR COLBERT HILLS
Map Scale = 8 inches per mile or 1:7,920

Bill Wehmueller (USDA-NRCS) and Mickey Ransom (K-State Department of Agronomy)

Bd **Benfield silty clay loam, 2 to 5 percent slopes.** Moderately deep, well drained, and slowly permeable soils. This map unit is on gently sloping benches and summits. The soils formed in thin loess over residuum weathered from shale.

Be **Benfield-Florence complex, 10 to 25 percent slopes.** Moderately deep and deep, well drained, and slowly permeable soils. This map unit is on moderately steep side slopes and nose slopes. The Benfield soils formed in thin loess over residuum weathered from shale, and the Florence soils formed in gravelly residuum weathered from cherty limestone.

Cm **Clime-Tuttle silty clay loams, 15 to 30 percent slopes.** Moderately deep and deep, well drained and somewhat excessively drained, slowly permeable soils. This map unit is on steep side slopes and nose slopes. These soils formed in hillslope sediment over residuum weathered from calcareous shale.

Cs **Clime silty clay loam, 5 to 20 percent slopes, stony.** Moderately deep, well drained, slowly permeable soils with a stony surface. This map unit is on strongly sloping benches. These soils formed in residuum weathered from limestone.

Fl **Florence cobbly silty clay loam, 2 to 10 percent slopes.** Moderately deep and deep, well drained, slowly permeable soils. This map unit is on ridge tops and shoulder slopes and formed in residuum weathered from cherty limestone.

If **Ivan-Udifluvents complex, frequently flooded.** This map unit consists of deep, well drained, moderately permeable Ivan soils on flood plains and relatively unweathered alluvial and point bar deposits composed of limestone and chert gravel. These soils formed in alluvium that is variable in texture and coarse fragment content.

Ka **Kahola silt loam, 0 to 2 percent slopes, occasionally flooded.** Deep, well drained, moderately permeable soils. These soils are on terraces that are occasionally flooded. They formed in silty alluvium.

Ko **Konza silt loam, 1 to 3 percent slopes.** Deep, moderately well drained, slowly permeable soils on nearly level to gently sloping summits of benches. They formed in loess over hillslope sediment over residuum weathered from cherty limestone.

Kp **Konza silt loam, 3 to 7 percent slopes.** Deep, moderately well drained, slowly permeable soils on moderately sloping lower back slopes that are transitional to the benches formed by the Schroyer limestone formation. They formed in loess over hillslope sediment over residuum weathered from cherty limestone.

La **Labette silty clay loam, 0 to 2 percent slopes.** Moderately deep, well drained, slowly permeable soils. They are on summits and shoulder slopes of the benches formed by the Schroyer limestone.

Tu **Tully silty clay loam, 4 to 8 percent slopes.** Very deep, well drained, slowly permeable soils. These soils formed in colluvium and are on lower side slopes and foot slopes.

Tv **Tully silty clay loam, 4 to 8 percent slopes, eroded.** Very deep, well drained, slowly permeable soils. These soils formed in colluvium and are on lower side slopes. These areas have been cultivated in the past, were eroded, and have been reseeded to native grasses.

Tw **Tully silty clay loam, 8 to 15 percent slopes.** Very deep, well drained, slowly permeable soils. These soils formed in colluvium and are on strongly sloping side slopes and head slopes of drainageways.

Parent material: Moderately weathered local colluvium from mixed over Moderately weathered local colluvium from mixed

Described by: M.D. Ransom, W.A. Wehmueller

Notes: Proposed KSU golf course site 31.

The following miscellaneous site information was collected.

Thickness of mollic epipedon (in): 18.50
Thickness of mollic epipedon (cm): 47.00
Depth to argillic horizon (in): 14.50
Depth to argillic horizon (cm): 37.00
Depth to free lime (in): 40.50
Depth to free lime (cm): 103.00

A1--0 to 12 cm; silt loam, very dark grayish brown (10YR 3/2), interior, moist; weak fine and medium granular structure; soft, very friable; many fine roots throughout; common fine and medium high continuity vesicular pores; 22.0 percent clay; clear smooth boundary.

A2--12 to 25 cm; silt loam, very dark grayish brown (10YR 3/2), interior, moist; moderate fine subangular blocky structure parting to moderate fine granular; slightly hard, friable; many fine roots throughout; common fine and medium low continuity vesicular pores; 25.0 percent clay; clear wavy boundary.

BA--25 to 37 cm; brown (10YR 4/3), exterior, silty clay loam, dark brown (10YR 3/3), interior, moist; weak fine and medium subangular blocky structure; slightly hard, friable; common fine roots throughout; common fine and medium low continuity vesicular pores; 32.0 percent clay; common medium rounded very dark gray (10YR 3/1) worm casts throughout; clear wavy boundary.

Bt1--37 to 47 cm; brown (7.5YR 4/3), exterior, silty clay loam, dark brown (7.5YR 3/3), interior, moist; moderate fine and medium subangular blocky structure; hard, friable; common fine roots between peds; common very fine and fine moderate continuity tubular pores; 35.0 percent clay; few faint patchy dark brown (7.5YR 3/2), moist, clay films on faces of peds; 2 percent subrounded limestone-cherty gravel; clear wavy boundary.

Bt2--47 to 59 cm; brown (7.5YR 5/3), exterior, silty clay, brown (7.5YR 4/3), interior, moist; moderate medium subangular blocky structure; hard, firm, very sticky and very plastic; common fine roots between peds; common very fine and fine moderate continuity tubular pores; 43.0 percent clay; few distinct discontinuous dark brown (7.5YR

3/2), moist, clay films on faces of peds; 2 percent subangular limestone-cherty gravel; clear wavy boundary.

Bt3--59 to 88 cm; brown (7.5YR 5/3), exterior, silty clay, brown (7.5YR 4/3), exterior, moist; weak medium prismatic structure parting to moderate medium subangular blocky; very hard, firm, very sticky and very plastic; common fine roots between peds; common very fine and fine moderate continuity tubular pores; 46.0 percent clay; few distinct continuous dark brown (7.5YR 3/2), moist, clay films on faces of peds and very few faint patchy dark brown (7.5YR 3/2), moist, nonintersecting slickensides on faces of peds; 3 percent subrounded limestone-cherty gravel; clear wavy boundary.

Bt4--88 to 103 cm; brown (7.5YR 5/3), exterior, silty clay, brown (7.5YR 4/3), interior, moist; weak medium prismatic structure parting to moderate medium subangular blocky; very hard, firm, very sticky and very plastic; common fine roots between peds; common very fine and fine moderate continuity tubular pores; 43.0 percent clay; few distinct continuous dark brown (7.5YR 3/3), moist, clay films on faces of peds and few distinct discontinuous dark brown (7.5YR 3/3), moist, nonintersecting slickensides on faces of peds; 3 percent subrounded limestone-cherty gravel; clear wavy boundary.

2Btk--103 to 124 cm; brown (7.5YR 5/4), exterior, silty clay loam, brown (7.5YR 4/4), interior, moist; moderate medium prismatic structure parting to moderate medium subangular blocky; hard, firm; common fine roots between peds; common very fine and fine moderate continuity tubular pores; 37.0 percent clay; few prominent discontinuous dark brown (7.5YR 3/3), moist, clay films on faces of peds; common fine and medium irregular hard carbonate nodules pedogenic; 4 percent subrounded limestone-cherty gravel; clear wavy boundary.

2Bt1--124 to 160 cm; brown (7.5YR 4/4), exterior, silty clay loam, dark brown (7.5YR 3/4), interior, moist; weak medium prismatic structure parting to weak medium subangular blocky; hard, friable; common very fine roots between peds; common very fine and fine moderate continuity tubular pores; 32.0 percent clay; very few faint discontinuous dark brown (7.5YR 3/3), moist, clay films on faces of peds; 3 percent subrounded limestone-cherty gravel; gradual wavy boundary.
Subsampled 124-148 cm, and 148-160 cm.

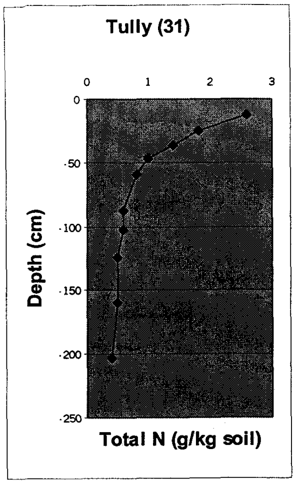
2Bt2--160 to 203 cm; brown (7.5YR 4/4), exterior, silty clay loam, dark brown (7.5YR 3/4), interior, moist; weak medium prismatic structure parting to weak medium subangular blocky; hard, friable; one large shale fragment, 5 cm in diameter at bottom of horizon; 33.0 percent clay; very few faint discontinuous dark brown (7.5YR 3/3), moist, clay films on faces of peds; 3 percent subrounded limestone-cherty gravel.
Subsampled 160-177cm, 177-213 cm.

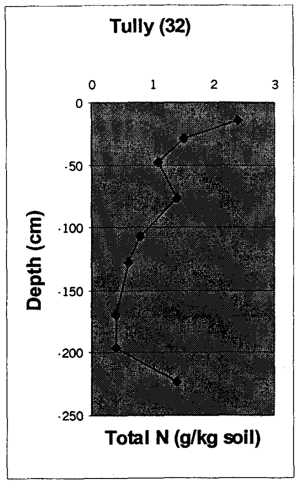
Soil Laboratory Analyses

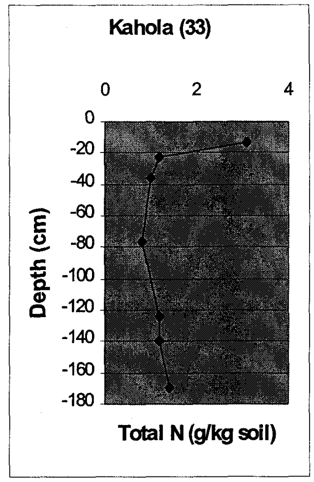
Sample #	Soil Series	Horizon	Depth	pH: H2O (1:1)	pH: 0.01M CaCl2 (2:1)	Total Nitrogen (%)	Total Carbon: (%)
533		2Bt3	43-56	7.3	7.3	0.0653	0.640
534		2Bt4	56-68	7.9	7.5	0.0395	0.391
535		2Bt5	68-87	8.2	7.7	0.0312	0.241
536		3Bt6	87-101	8.4	7.8	0.0325	0.274
537		3Bt7	101-120	8.2	7.8	0.0303	0.178
538		3Bt8	120-144	8.1	7.8	0.0249	0.166
539		3Bt9	144-161	8.0	7.8	0.0202	0.086
540		4Bt10	161-181	7.9	7.8	0.0253	0.100
541		5R	181-186	R material			
542	Clime	A1	0-11	7.8	7.5	0.3390	4.620
543	97KS-999-036	A2	11-33	8.0	7.5	0.2430	5.070
544		Bw1	33-49	8.0	7.6	0.1060	5.870
545		Bw2	49-67	8.3	7. 8	0.0677	4.790
546		2Bck1	67-87	8.4	7.7	0.0344	3.930
547		2Bck2	87-122	8.2	7.7	0.0294	3.610
548		2Cr	122-160	8.3	7.7	0.0303	1.160
549	Tuttle	A1	0-15	8.1	7.6	0.3930	6.040
550	97KS161-047	A2	15-43	8.1	7.7	0.2520	6.860
551		2Bw1	43-58	7.9	7.5	0.1190	8.460
552		2Bw2	58-110	8.0	7.6	0.0868	6.510
553		2Cr	58-110	7.9	7.6	0.0368	8.650
554		3BC	110-120	8.2	7.7	0.0369	5.040
555		3Cr	120-160	6.0	5.5	0.0270	4.430
556	Florence	A1	0-10	8.1	7.7	0.4040	4.960
557	97KS161-048	A2	10-28	5.5	5.3	0.2690	3.110
558		Bt	28-53	5.6	5.8	0.2340	2.620
559	Benfield	A1	0-9	6.0	5.8	0.2810	3.620
560	97KS161-049	A2	9-29			0.2160	2.590
561		2Bt1	29-40	6.5	6.1	0.1800	2.070
562		2Bt2	40-53	6.6	6.3	0.1610	1.840
563		2Bt3	53-78	7.9	7.5	0.1110	6.080
		3Cr	78-100				

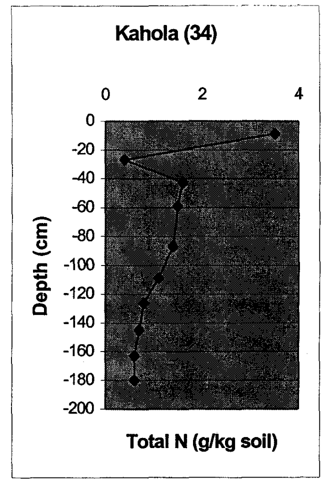
Table 1. Soil sample identification and preliminary laboratory data.

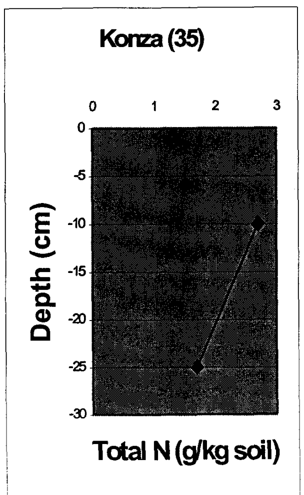
Sample #	Soil Series	Horizon	Depth	pH: H2O (1:1)	pH: 0.01M CaCl2 (2:1)	Total Nitrogen (%)	Total Carbon: (%)
489	Tully	A1	'0-12	6.2	5.6	0.2710	3.380
490	97KS999-031	A2	12-25	6.3	5.5	0.1550	2.040
491		BA	25-37	6.4	5.6	0.1280	1.650
492		Bt1	37-47	6.4	5.5	0.1050	1.290
493		Bt2	47-59	6.5	5.5	0.0823	0.891
494		Bt3	59-88	6.8	5.8	0.0676	0.696
495		Bt4	88-103	7.3	6.4	0.0645	0.573
496		2Btk	103-124	7.9	7.2	0.0555	0.454
497		2Bt1-up	124-128	7.9	7.2	0.0634	0.564
498		2Bt1-low	128-160	7.9	7.0	0.0536	0.404
499		2Bt1-up	160-177	7.9	7.0	0.0499	0.406
500		2Bt1-low	177-203+	7.9	7.0	0.0466	0.383
501	Tully	A1	0-15	6.4	5.6	0.2050	2.760
502	97KS999-032	A2	15-29	6.3	5.4	0.1410	1.900
503		AB	29-48	6.8	5.5	0.0993	1.260
504		2Bw	48-77	6.5	5.5	0.1190	1.500
505		2Bt1	77-107	6.5	5.6	0.0767	0.900
506		2Bt2	107-127	6.6	5.5	0.0600	0.626
507		2Bt3	127-170	6.7	5.7	0.0440	0.368
508		2Bt4	170-196	6.8	5.8	0.0390	0.347
509		2Bt5	196-224	6.8	5.8	0.0389	0.334
510	Kahola	A1	0-13	7.3	6.7	0.2360	2.860
511	97KS999-033	A2	13-23	7.7	7.0	0.1190	1.250
512		AC	23-36	8.2	7.5	0.7590	0.926
513		C1-up	36-56	8.3	7.5	0.0812	1.020
514		C1-low	56-77	8.3	7.5	0.0837	1.190
515		C2-up	77-91	8.3	7.5	0.0939	1.390
516		C2-low	91-124	8.3	7.4	0.0806	1.240
517		Ab1	124-140	8.1	7.3	0.1050	1.660
518		Ab2	140-170	8.0	7.4	0.1300	2.310
519	Kahola	A1	0-9	8.1	6.9	0.2410	2.890
520	97KS999-034	A2	9-27	7.8	7.4	0.1150	1.470
521		Ab1	27-43	8.0	7.2	0.1470	2.160
522		Ab2	43-59	8.1	7.3	0.1360	2.020
523		ABkb	59-87	8.1	7.4	0.1200	1.920
524		Bkb	87-109	8.2	7.5	0.0836	1.290
525		2Bwb1	109-126	8.2	7.5	0.0651	0.787
526		2Bwb2	126-145	7.9	7.5	0.5700	0.636
527		2Bwb3	145-163	7.9	7.4	0.0603	0.654
528		2Bwb4	163-180	7.9	6.6	0.0578	0.589
529	Konza	A1	0-10	6.1	5.2	0.2570	3.280
530	97KS-999-035	A2	10-17	6.0	4.8	0.1610	2.090
531		Bt1	27-25	6.2	5.0	0.1330	1.560
532		Bt2	25-43	7.0	5.7	0.1100	1.190

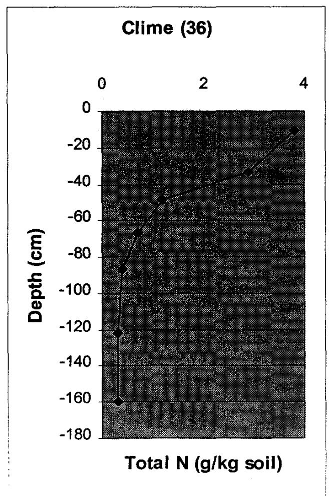

Tully (31)
Depth (cm)
Total N (g/kg soil)

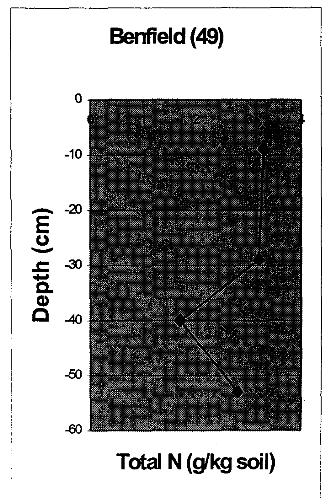

Tully (32)
Depth (cm)
Total N (g/kg soil)

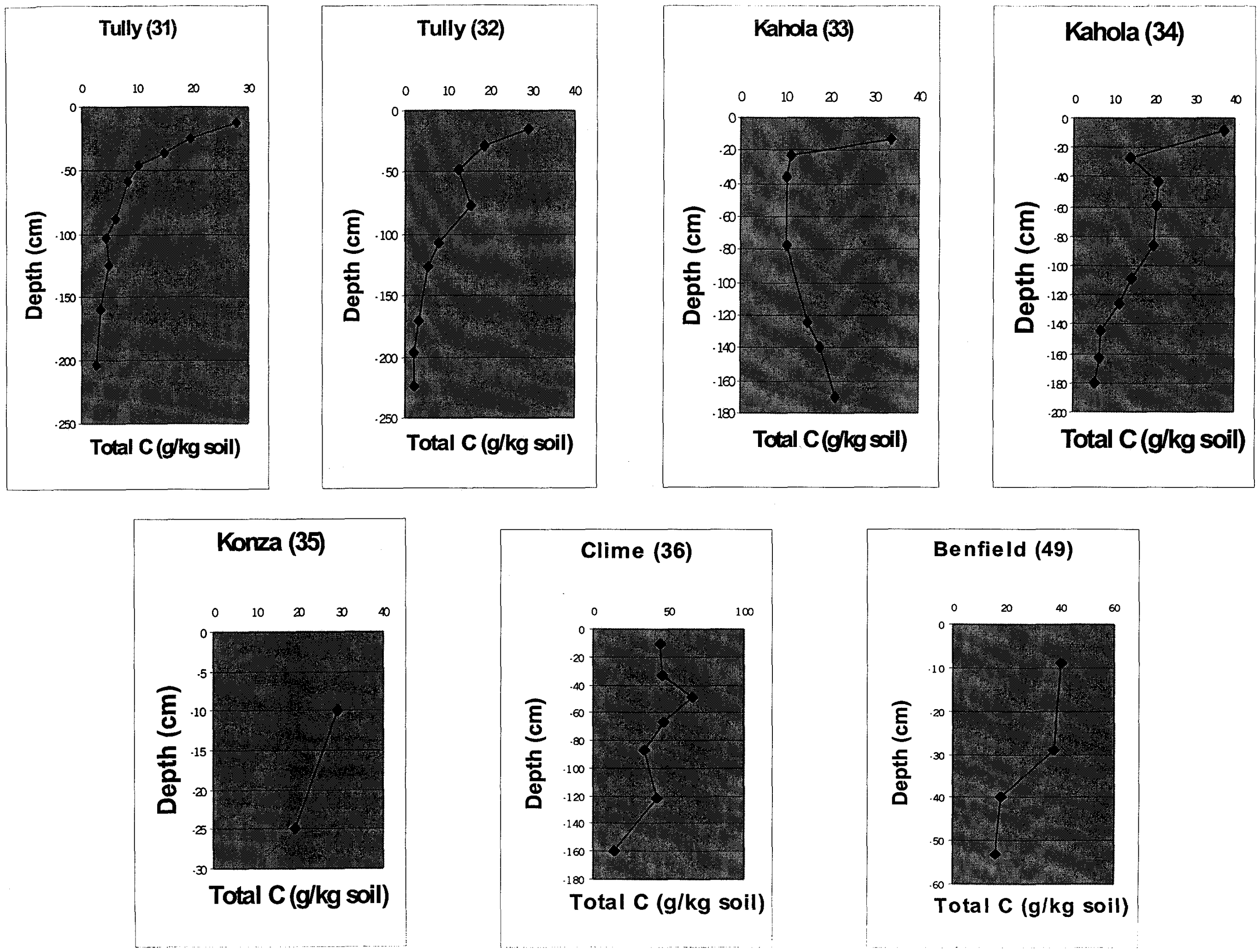

Kahola (33)
Depth (cm)
Total N (g/kg soil)


Kahola (34)
Depth (cm)
Total N (g/kg soil)


Konza (35)
Depth (cm)
Total N (g/kg soil)


Clime (36)
Depth (cm)
Total N (g/kg soil)


Benfield (49)
Depth (cm)
Total N (g/kg soil)


Tully (31)
Depth (cm)
Total C (g/kg soil)
Tully (32)
Depth (cm)
Total C (g/kg soil)
Kahola (33)
Depth (cm)
Total C (g/kg soil)
Kahola (34)
Depth (cm)
Total C (g/kg soil)
Konza (35)
Depth (cm)
Total C (g/kg soil)
Clime (36)
Depth (cm)
Total C (g/kg soil)
Benfield (49)
Depth (cm)
Total C (g/kg soil)

Soil Series Name	Depth (cm)	MBM C ($\mu g/g$)
Tully (31)	0-12	1095
Tully (32)	0-15	297
Kahola (33)	0-13	721
Kahola (34)	0-9	1045
Konza (35)	0-10	728
Clime (36)	0-11	1062
Benfield (49)	0-9	837

Soil Series Name	Depth (cm)	MBM C ($\mu g/g$)
Tully (31)	12-25	444
Tully (32)	15-29	376
Kahola (33)	13-23	243
Kahola (34)	9-27	216
Konza (35)	10-25	461
Clime (36)	11-33	832
Benfield (49)	9-29	665

Soil Series Name	Depth (cm)	MBM N ($\mu g/g$)
Tully (31)	0-12	292
Tully (32)	0-15	268
Kahola (33)	0-13	309
Kahola (34)	0-9	340
Konza (35)	0-10	216
Clime (36)	0-11	359
Benfield (49)	0-9	339

Soil Series Name	Depth (cm)	MBM N ($\mu g/g$)
Tully (31)	12-25	125
Tully (32)	15-29	103
Kahola (33)	13-23	99
Kahola (34)	9-27	111
Konza (35)	10-25	123
Clime (36)	11-33	237
Benfield (49)	9-29	171

287 d 6/19/98	**C_0**	**N_0**
Golf Course	**$\mu g\ C\ g^{-1}$ soil**	**$\mu g\ N\ g^{-1}$ soil**
Tully (31)	3637	302
Tully (32)	4523	229
Kahola (33)	4337*	544!
Kahola (34)	5660	674
Konza (35)	4468	211
Clime (36)	6324	581!
Benfield (49)	3494	674

* only two reps. fit the model
! only one rep. fit the model