Final Report

Historical C Project

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This report summarizes the results of this research project and gives a detailed accounting of the activities undertaken from Summer 2010 to the present. The overall findings of the project show that for 102 sites so far analyzed, there were significant increases in carbon concentration for forest soils (38%) and a small but significant decrease in cropped soils (-13%) over mean depths of 24-30 inches (60-75 cm). Grassland soil C increases were not significant due to small sample numbers (n=9). Carbon accumulation increased significantly for the top two horizons (0-4" and 4-13") at forest sites, while grassland sites had significant increases only in the second horizon (8-16"). Cropland sites had significant decreases of 24% in the surface horizon. When management changed from cropland to grassland, C concentration increased 53% (from 12.2 to 18.8 g C kg^{-1} soil for 12 sites), but site numbers were too small to see C differences for other management conversions. Regional differences in C changes reflect the predominant managements sampled in each area.

During the final reporting period, our activities were focused on:

1. Processing and analyzing soil samples taken during Summer and Fall of 2010 in the following counties: Brown, Nobles, Rock, Houston, Beltrami, Wilkin and Pennington.

2. Analyzing the original soil samples for each county that had been sampled in 2010.

3. Summarizing the results.

1. **Processing and analysis of soil samples Summer-Fall 2010.**

Soil samples were taken in the Summer and Fall of 2010 in the following counties: Brown, Nobles, Rock, Houston, Beltrami, Wilkin, and Pennington. Table 1 summarizes all the counties that were sampled for the duration of the study.

During Summer-Fall 2010 sampling, approximate locations of the sites were identified using latitude and longitude information. A GPS unit was used to verify the exact location. Soil samples were taken using a hand-probe. An average of 3-4 cores were taken to match the increment depths already recorded in the Soil Survey notes for each sample. Some extra cores were taken for the shallow surface soil samples. Samples were transported to the laboratory, sieved to 2mm, air-dried and stored until analysis.

Soil samples were analyzed for C and N using a Vario Max C/N analyzer. Data summaries for each county are presented in the Appendix and a summary of the results is presented later in this report.

In some cases, soil samples had very high C values because of high carbonate content. We selected those samples that had a pH of 7.5 or greater and re-ran them using an adjustment for carbonates on the Vario Max C/N analyzer. This adjustment was not always successful, so we also attempted to neutralize the carbonates using a HCl-fumigation technique. Some samples were still very high in C, so we are planning to treat the soil samples with a solution of hydrochloric acid and then rinse them with distilled water to eliminate all the carbonates present. There were samples from 20 sites with questionable C values which are not reported here; the final data will be presented shortly in a revised final report.

2. **Analysis of the original soil samples for each county.**

Total C and N of the original soil samples were determined by dry combustion using a Vario Max C/N analyzer, so that we could compare the original reported C values with values obtained using the present methodology. We obtained a high correlation between the original data and the reanalyzed measurements for the archived samples (r=0.943, n=225) with the Vario Max C/N analyzer procedure (Figure 1), which gave us confidence that we could use the re-ran values as “original” soil sample data to compare with the values for the soils sampled in 2009 and 2010. Some of the original data for the lowest depths were not reported but we were able to analyze them because we had access to the archived samples.

3. Summary of the preliminary results

In total, there were 492 sites for which labeled, archived samples exist. These sites occur in the following regions of MN:

- **North Central**: 18 sites in Aitkin, Morrison, and Todd Counties.
- **Northeast**: 67 sites in St Louis, Itasca and Koochiching Counties.
- **Southwest**: 48 sites in Rock, Nobles, Jackson, and Murray Counties.
- **Red River North Basin**: 121 sites in Beltrami, Clearwater, Clay, Mahnomen, Pennington, Red Lake, Wilkin and Traverse Counties.
- **Southeast**: 80 sites in Houston, Mower and Winona Counties.
- **Minnesota River Basin**: 158 sites in Kandiyohi, Chippewa, Yellow Medicine, Redwood, Meeker, Brown, Le Sueur, and Martin Counties.

After collecting information about the landowners for each experimental site, the counties that were considered for resampling were:

- **North Central Region of MN**: Todd (11).
- **North East Region of MN:** St Louis North and South and Itasca (65).
- **Southwestern Region of MN**: Rock and Nobles (16).
- **Red River North Basin**: Beltrami, Pennington, and Wilkin (98).
- **Southeastern Region of MN:** Winona and Houston (48).
- **Minnesota River Basin:** Kandiyohi, Yellow Medicine, Redwood, and Brown (92).

Thus, the potential number of sites to be sampled was reduced to 330 for the 15 counties (Table 1). We sent 244 letters to those landowners we could identify requesting permission to obtain soil samples, and received positive replies for a total of 135 sites to sample. Some of the sites could not be sampled because the actual location was no longer suitable (middle of road, disturbed sites, and construction areas).

Data presented in this report correspond to 102 sites, since we will be repeating soil samples that have high carbonates. To summarize the results presented in this report, data for each site was averaged over the whole profile. Individual information for each site and county are presented in the Appendix.

Changes in carbon concentrations for each type of management practice are presented in Figures 2 and 3. Figure 2 shows changes in C concentration for those sites that had the same management at the initial sampling time (T=0) as when we sampled in 2009-10 (T=1). For 24 sites with forest vegetation, C concentrations increased significantly by 5.1 g C kg^{-1} soil (38% increase) to a mean depth of 24 inches (61 cm). Sites under grassland (n=9) averaged a similar increase (5.2 g C kg^{-1} soil) to 30 inches (76 cm), but it was not significant due to the small number of samples. Those sites that were in cropland (n=51) had a significant but smaller decrease of 2.3 g C kg^{-1} soil in C concentration (-13%) after 31 yrs to a mean depth of 27 inches (69 cm).

Changes in C concentrations at different depths are presented in Table 2 and Figure 3. For each management, soil sampling depths were averaged for each of 3 horizons. Carbon concentrations were significantly higher in the top two horizons for forest sites and in the second horizon only for grassland sites. For cropland sites, C losses were only observed in the surface horizon (24%).

Figure 4 shows how C concentrations have changed for sites where the vegetation is different from what it was when the soils were originally sampled (T=0). The number of sites for each category is low, so the only significant differences were observed for sites where cropland changed to grassland. Over a mean depth of 27 inches (69 cm), C concentrations increased by 6.5 g C kg^{-1} soil (53 %).

When the data was averaged across the six Minnesota regions where we sampled (Table 3, Figure 5), most of the areas showed no changes or slight increases in C concentrations across all managements. Comparing differences in C concentrations among regions should be done with caution, since each region encompasses different managements and soil types, and the number of sites per region varies greatly. For example, the increase observed in the Northeast can be attributed to the fact that all these sites were under forest (21 sites). In the North Central region, changes in C are related to management since 4 of the 5 sites sampled are in grassland, but such small sample numbers do not allow us to generalize for the whole region. The relatively small changes in the Minnesota River Basin, Southwest and Red River North Basin reflect mostly cropland sites. In the Southeast, about half the sites are under grassland or forest and the other half are in cropland.

Table 1. Detailed information for the sampled sites:

Region	County	Potential sites	Sent letters	Approved answer for sampling	Sampled Sept 2009 to October 2010
Northeast	**Itasca**	18	10	8	3 † (September 16th 2009)
	St . Louis North	30	15	13	11 (September 16th 2009)
	St. Louis South	17	5 (and by email contact)‡	12	8 (September 2nd 2009)
North Central	**Todd**	11	10	5	5 (September 9th 2009)
Red River North Basin	**Pennington**	52	52	14	14 (September 28th and 29th 2010)
	Beltrami	17	12	7	7 (September 28th and 29th))
	Wilkin	29	19	12∫	15 (September 21st 2010)
Minnesota River Basin	**Redwood**	11	10	6	6 (November 10th 2009)
	Yellow Medicine	9	8	3	2 (November 10th 2009)
	Kandiyohi	26	14	8∫	13 (November 17th 2009)
	Brown	46	40	17∫	14 (July 21st and 27th 2010)
Southeastern	**Winona**	19	14	10	8 (October 28th 2009)
	Houston	29	19	11	7(October 20th 2010)
Southwestern	**Rock**	14	14	7	7 (June 24th 2010)
	Nobles	2	2	2	2 (June 24th 2010)
Total	**15**	330	244	135	122

† For proximity, we only sampled the sites from Itasca Co. that were close to St. Louis North Co.
‡ For some of the sites, permission was obtained by email contact.
∫ There were more than two sites for some landowners.

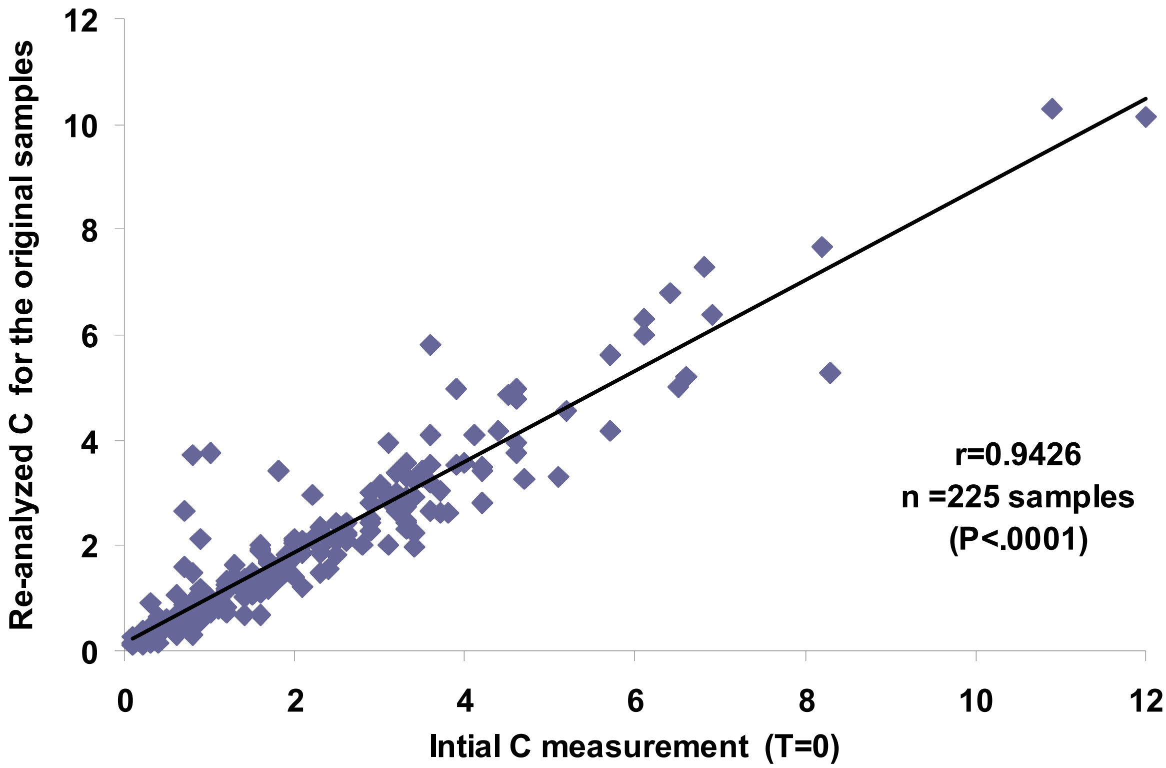

Figure 1. Comparison between initial C measurement (T=0) and the re-analyzed C measurement in 2009-2010 of the original samples using the Vario Max C/N analyzer at different sampling depths.

Management	C at initial sampling (T=0)	C at present	Increment in C concentration	Number of sites	Mean time since T=0	Mean depth of sampling
	………….. g C kg^{-1} soil		…………..		yrs	inches
Forest	13.4	18.5	5.1 (*P*=0.0068)	24	30	24
Cropland	16.9	14.6	- 2.3 (*P*=0.0280)	51	31	27
Grassland	10.5	15.7	5.2 (*P*=0.1330)	9	30	30

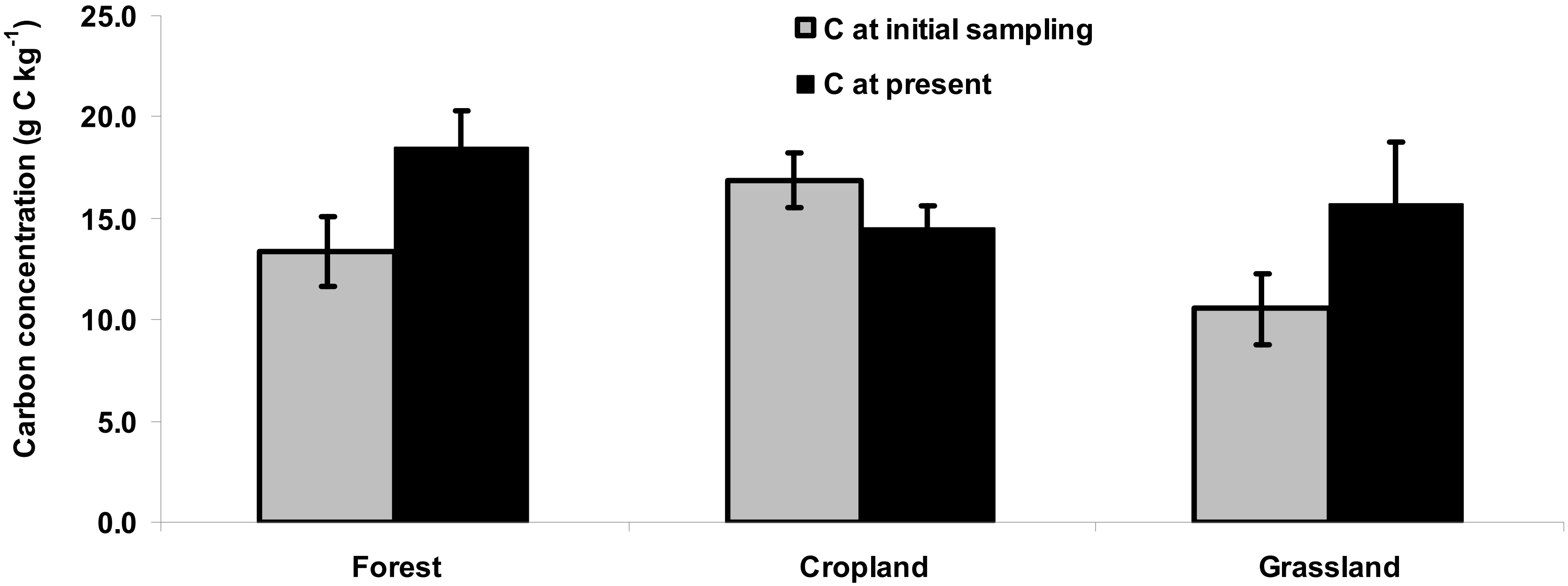

Figure 2. Changes in carbon concentrations after 30 years for sites that remained in the same management.

Table 2. Changes in carbon concentrations after 30 years for sites that remained in the same management at different depth increments.

	Forest[1]			Grassland[2]			Cropland[3]		
Horizon	**1**	**2**	**3**	**1**	**2**	**3**	**1**	**2**	**3**
Initial C ($g\ C\ kg^{-1}$ soil)	41.7	10.2	4.4	20.6	5.9	6.2	28.8	14.4	6.7
C at present ($g\ C\ kg^{-1}$ soil)	56.5	16.3	6.2	23.5	13.2	10.3	22.1	13.3	8.2
C increment or decrease ($g\ C\ kg^{-1}$ soil)	14.9*	6.0**	2.1	2.9	7.3*	4.2	-6.7**	-1.1	1.4
% increment or decrease from Initial C	36	59	48	14	124	68	-24	-8	22

* Indicates significant differences at $P<0.05$

** Indicates significant differences at $P<0.01$

1. For forest, mean horizon depths are 1=0-4", 2=4-13", 3=13-31"

2. For grassland, mean horizon depths are 1=0-8", 2=8-16", 3=16-32"

3. For cropland, mean horizon depths are 1=0-9", 2=9-16", 3=16-28"

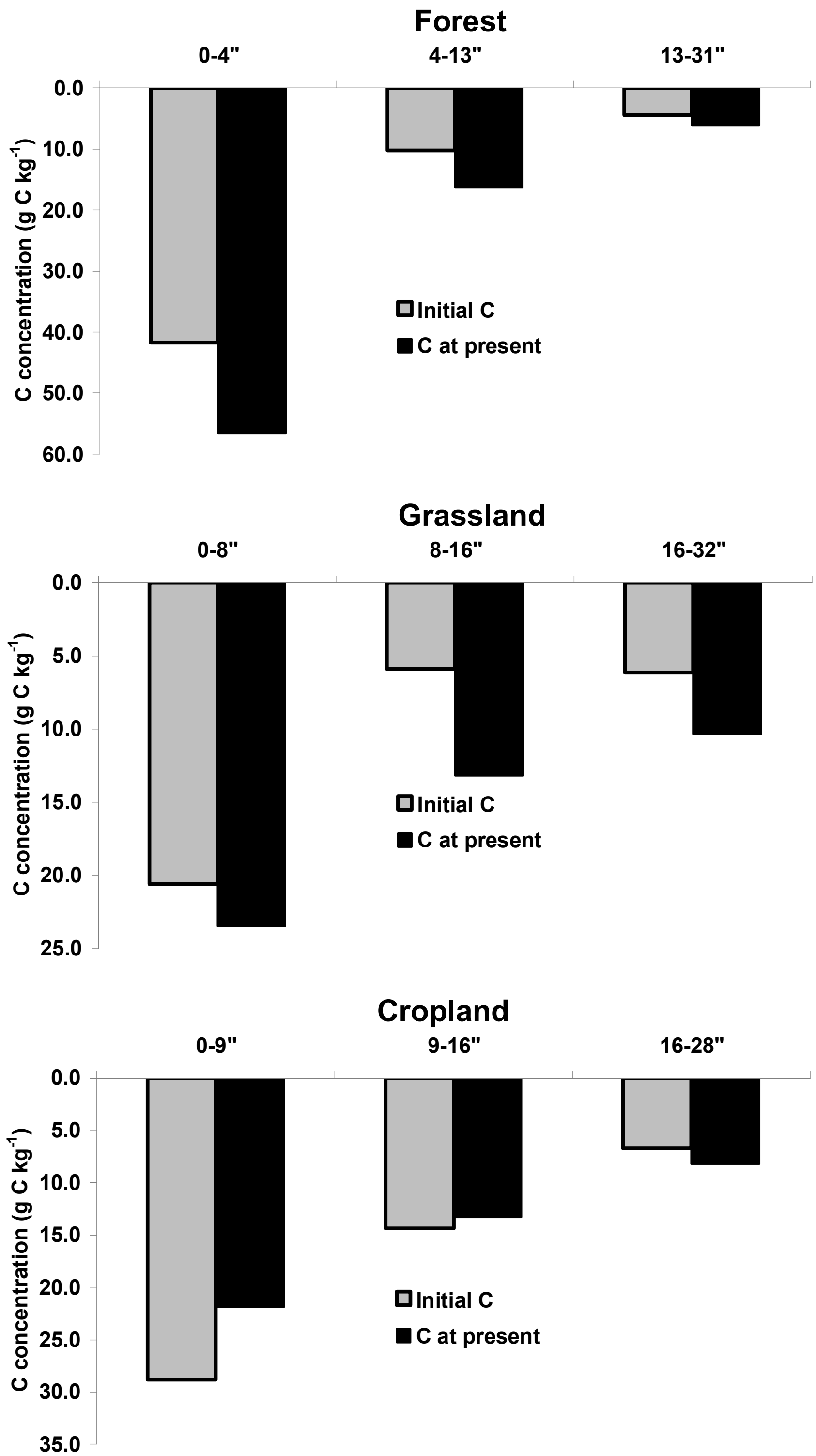

Figure 3. Changes in carbon concentrations after 30 years for sites that remained in the same management at different depth increments.

Management	C at initial sampling (T=0)	C at present	Increment in C concentration	Number of sites	Mean time since T=0	Mean depth of sampling
	.... g C kg^{-1} soil		....		yrs	inches
Forest to Grassland	13.6	14.1	0.5 (*P*=0.8787)	3	30	29
Cropland to Forest	4.5	13.2	8.7 (*P*=0.0753)	3	31	33
Cropland to Grassland	12.2	18.8	6.5 (*P*=0.0299)	12	30	27

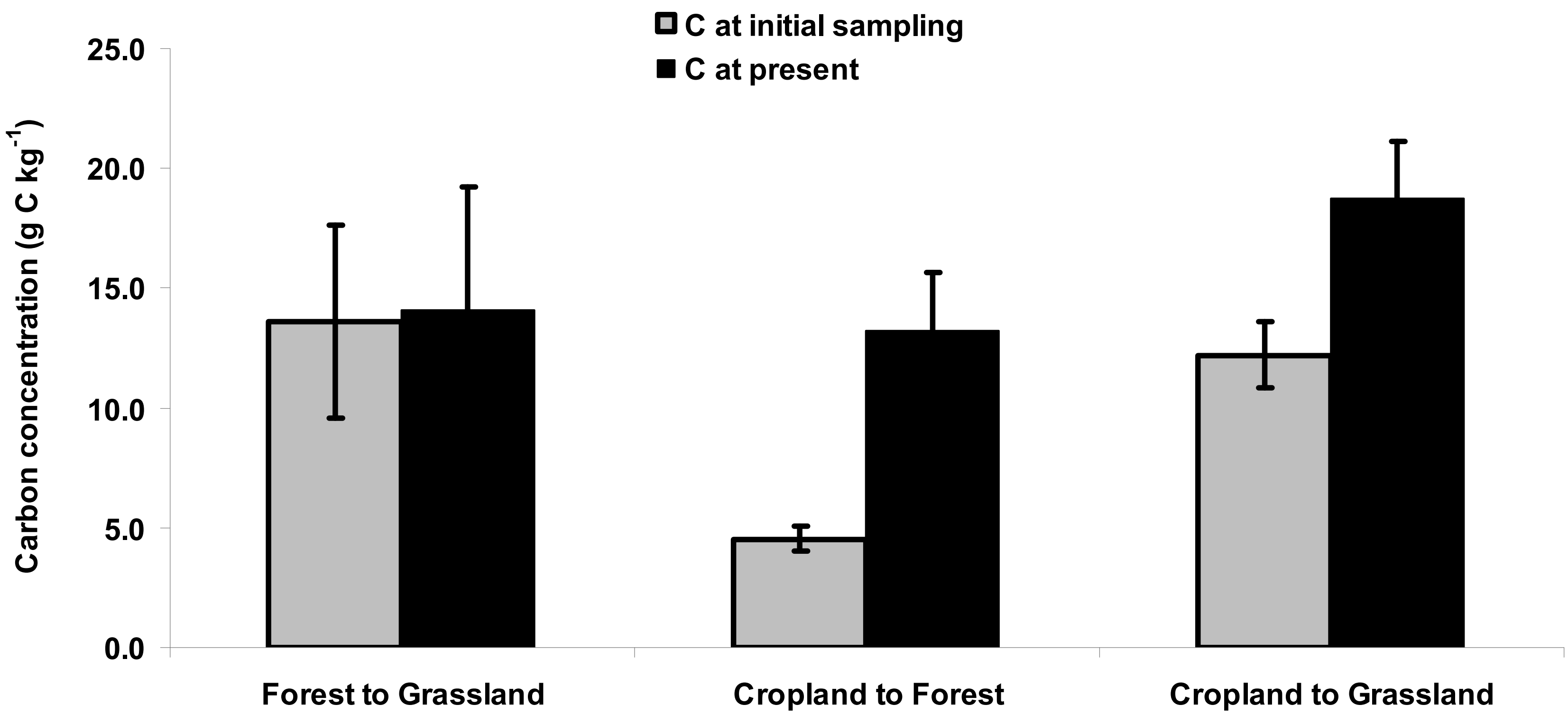

Figure 4. Changes in carbon concentration after 30 years at sites that changed management.

Table 3. Average changes in carbon concentration in 6 different regions of Minnesota after 30 yrs.

Management	C at initial sampling (T=0)	C at present	Increment in C concentration	Number of sites
	………..… g C kg^{-1} soil …………..			
Northeast	13.6	19.0	5.4 (*P*=0.0056)	21
Red River North Basin	12.5	12.7	0.2 (*P*=0.8581)	26
North Central	8.6	17.4	8.9 (*P*=0.2322)	5
Minnesota River Basin	18.9	18.4	-0.5 (*P*=0.8161)	30
Southwest	17.2	16.9	-0.3 (*P*=0.9032)	8
Southeast	9.6	12.7	3.1 (*P*=0.1352)	13

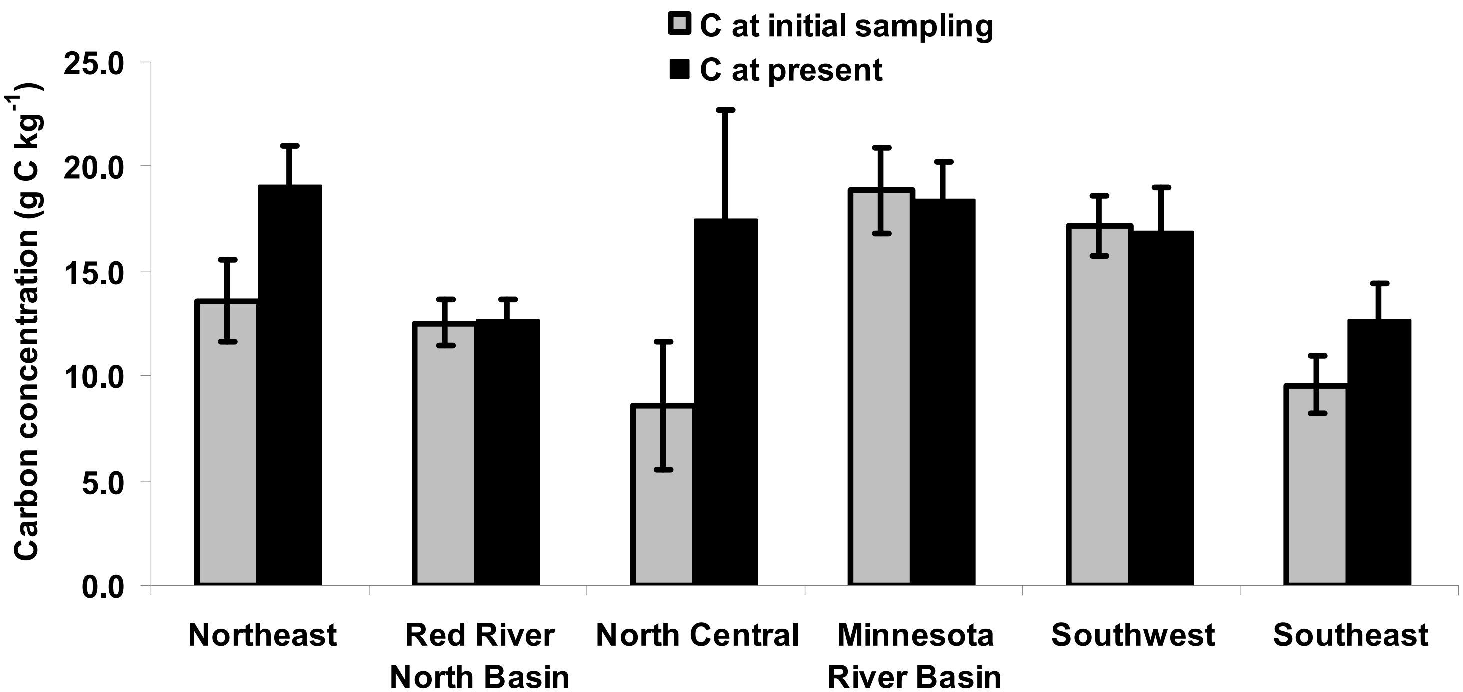

Figure 5. Average changes in carbon concentration in 6 different regions of Minnesota after 30 yrs.

APPENDIX
Individual information for each sampling site.

Region	County	N of sites	Management	Average depth	C at initial (T=0)	C at present (T=1)	C-Increment	Time since T=0
				inches	………………………… g C kg^{-1} soil		………………………	yrs.
Northeast	**Itasca**	1	Forest	**22**	3.92	21.20	17.28	31
Northeast	**Itasca**	2	Forest	**24**	5.26	20.82	15.56	31
Northeast	**Itasca**	3	Forest	**23**	7.32	10.31	2.99	29
Northeast	**St. Louis N**	4	Forest	**15**	16.97	24.81	7.84	31
Northeast	**St. Louis N**	5	Forest	**23**	16.11	16.79	0.67	30
Northeast	**St. Louis N**	6	Forest	**15**	16.07	21.27	5.20	30
Northeast	**St. Louis N**	7	Forest	**14**	11.41	17.37	5.96	30
Northeast	**St. Louis N**	8	Forest	**8**	27.37	29.43	2.06	30
Northeast	**St. Louis N**	9	Forest	**26**	10.17	28.13	17.96	30
Northeast	**St. Louis N**	10	Forest	**18**	19.28	9.59	-9.69	30
Northeast	**St. Louis N**	11	Forest	**60**	1.86	12.00	10.14	29
Northeast	**St. Louis N**	12	Forest	**44**	3.85	17.76	13.91	29
Northeast	**St. Louis N**	13	Forest	**60**	2.80	6.65	3.85	29
Northeast	**St. Louis N**	14	Forest to Grassland	**30**	18.60	23.92	5.32	30
Northeast	**St. Louis S**	15	Forest	**36**	2.07	5.55	3.48	31
Northeast	**St. Louis S**	16	Forest	**16**	4.27	3.76	-0.50	30
Northeast	**St. Louis S**	17	Forest	**16**	17.55	26.63	9.09	30
Northeast	**St. Louis S**	18	Forest	**15**	28.93	33.30	4.37	30
Northeast	**St. Louis S**	19	Forest	**14**	20.89	35.77	14.88	30
Northeast	**St. Louis S**	20	Forest	**13**	23.66	18.52	-5.14	30
Northeast	**St. Louis S**	21	Forest	**25**	27.02	16.21	-10.80	30
Red River North Basin	**Beltrami**	1	Forest	**24**	10.69	9.55	-1.14	30
Red River North Basin	**Beltrami**	2	Forest	**23**	15.90	10.86	-5.04	30
Red River North Basin	**Beltrami**	3	Grassland	**18**	13.25	9.84	-3.41	30
Red River North Basin	**Beltrami**	4	Grassland	**21**	9.37	9.78	0.41	30
Red River North Basin	**Beltrami**	5	Grassland	**34**	16.63	16.61	-0.02	31
Red River North Basin	**Beltrami**	6	Cropland to Grassland	**22**	20.58	17.08	-3.51	30
Red River North Basin	**Beltrami**	7	Cropland to Grassland	**24**	17.21	20.39	3.18	30
Red River North Basin	**Pennington**	8	Forest	**18**	14.63	16.01	1.37	30
Red River North Basin	**Pennington**	9	Cropland	**17**	27.17	23.49	-3.68	32
Red River North Basin	**Pennington**	10	Cropland	**18**	16.03	15.76	-0.27	31
Red River North Basin	**Pennington**	11	Cropland	**22**	6.21	9.48	3.27	30
Red River North Basin	**Pennington**	12	Cropland	**27**	12.38	9.95	-2.43	30
Red River North Basin	**Pennington**	13	Cropland to Forest	**23**	3.72	16.16	12.44	32
Red River North Basin	**Pennington**	14	Cropland to Forest	**24**	5.48	15.19	9.71	32
Red River North Basin	**Pennington**	15	Cropland to Grassland	**25**	10.67	18.08	7.40	-
Red River North Basin	**Pennington**	16	Cropland to Grassland	**16**	7.83	10.49	2.66	32
Red River North Basin	**Wilkin**	17	Cropland	**21**	17.03	7.17	-9.86	31
Red River North Basin	**Wilkin**	18	Cropland	**35**	6.85	5.22	-1.63	31
Red River North Basin	**Wilkin**	19	Cropland	**30**	5.51	6.33	0.81	31
Red River North Basin	**Wilkin**	20	Cropland	**31**	5.21	11.63	6.42	31
Red River North Basin	**Wilkin**	21	Cropland	**32**	11.94	10.02	-1.91	31
Red River North Basin	**Wilkin**	22	Cropland	**37**	12.56	7.94	-4.62	31
Red River North Basin	**Wilkin**	23	Cropland	**30**	13.56	8.79	-4.77	30
Red River North Basin	**Wilkin**	24	Cropland	**24**	14.23	13.82	-0.41	30
Red River North Basin	**Wilkin**	25	Cropland	**26**	11.13	11.81	0.68	30
Red River North Basin	**Wilkin**	26	Cropland	**18**	19.86	18.62	-1.24	30

Region	County	N of sites	Management	Average depth	C at initial (T=0)	C at present (T=1)	C-Increment	Time since T=0
				inches	……………………….. g C kg^{-1} soil …………………….			yrs.
Northcentral	**Todd**	1	Cropland	**26**	20.62	14.68	-5.94	29
Northcentral	**Todd**	2	Grassland	**15**	6.44	26.72	20.28	29
Northcentral	**Todd**	3	Grassland	**36**	4.99	6.87	1.88	31
Northcentral	**Todd**	4	Forest to Grassland	**36**	5.55	6.48	0.93	29
Northcentral	**Todd**	5	Cropland to Grassland	**15**	5.33	32.49	27.16	29
Minnesota River Basin	**Brown**	1	Cropland	**15**	17.55	13.16	-4.40	32
Minnesota River Basin	**Brown**	2	Cropland	**17**	18.77	22.06	3.28	32
Minnesota River Basin	**Brown**	3	Cropland	**26**	13.19	16.15	2.96	32
Minnesota River Basin	**Brown**	4	Cropland	**33**	9.79	11.25	1.46	32
Minnesota River Basin	**Brown**	5	Cropland	**35**	12.31	9.81	-2.50	32
Minnesota River Basin	**Brown**	6	Cropland	**30**	51.78	33.97	-17.81	32
Minnesota River Basin	**Brown**	7	Cropland	**33**	46.46	26.78	-19.68	32
Minnesota River Basin	**Brown**	8	Cropland	**24**	6.13	4.64	-1.49	32
Minnesota River Basin	**Brown**	9	Cropland	**20**	24.26	23.01	-1.25	31
Minnesota River Basin	**Brown**	10	Cropland	**24**	13.76	12.72	-1.04	31
Minnesota River Basin	**Brown**	11	Cropland	**25**	7.68	5.75	-1.93	31
Minnesota River Basin	**Brown**	12	Cropland	**38**	14.85	15.74	0.89	31
Minnesota River Basin	**Brown**	13	Cropland	**18**	24.08	18.82	-5.26	30
Minnesota River Basin	**Kandiyohi**	14	Cropland	**31**	19.66	11.54	-8.11	31
Minnesota River Basin	**Kandiyohi**	15	Cropland	**24**	34.73	6.19	-28.54	30
Minnesota River Basin	**Kandiyohi**	16	Grassland	**31**	5.82	33.68	27.86	31
Minnesota River Basin	**Kandiyohi**	17	Grassland	**23**	17.90	32.74	14.84	29
Minnesota River Basin	**Kandiyohi**	18	Grassland	**60**	5.41	21.15	15.74	29
Minnesota River Basin	**Kandiyohi**	19	Grassland	**34**	15.09	9.42	-5.67	29
Minnesota River Basin	**Kandiyohi**	20	Cropland to Grassland	**60**	6.50	8.79	2.29	31
Minnesota River Basin	**Kandiyohi**	21	Cropland to Grassland	**19**	17.79	15.33	-2.46	31
Minnesota River Basin	**Kandiyohi**	22	Cropland to Grassland	**17**	13.30	33.79	20.48	28
Minnesota River Basin	**Kandiyohi**	23	Cropland to Grassland	**30**	11.73	16.61	4.88	29
Minnesota River Basin	**Redwood**	24	Cropland	**23**	18.74	19.48	0.74	33
Minnesota River Basin	**Redwood**	25	Cropland	**25**	23.39	16.85	-6.54	33
Minnesota River Basin	**Redwood**	26	Cropland	**25**	16.03	13.44	-2.59	33
Minnesota River Basin	**Redwood**	27	Cropland	**28**	27.54	43.63	16.10	32
Minnesota River Basin	**Redwood**	28	Cropland	**28**	36.09	30.47	-5.61	32
Minnesota River Basin	**Y. Medicine**	29	Cropland	29	18.63	8.29	-10.34	33
Minnesota River Basin	**Y. Medicine**	30	Cropland	21	17.28	16.26	-1.01	33

Region	County	N of sites	Management	Average depth	C at initial (T=0)	C at present (T=1)	C-Increment	Time since T=0
				inches	....	g C kg^{-1} soil	....	yrs.
Southwestern	**Nobles**	1	Cropland	**22**	14.78	17.80	3.01	31
Southwestern	**Nobles**	2	Cropland to Grassland	**20**	15.65	27.33	11.67	31
Southwestern	**Rock**	3	Cropland	**18**	15.54	12.24	-3.29	32
Southwestern	**Rock**	4	Cropland	**16**	13.05	8.36	-4.68	32
Southwestern	**Rock**	5	Cropland	**16**	23.84	13.05	-10.79	32
Southwestern	**Rock**	6	Cropland	**26**	16.52	13.92	-2.60	32
Southwestern	**Rock**	7	Cropland	**30**	14.43	20.82	6.39	32
Southwestern	**Rock**	8	Cropland	**18**	23.56	21.35	-2.21	32
Southeastern	**Houston**	1	Cropland	**34**	13.09	13.55	0.46	-
Southeastern	**Houston**	2	Cropland	**42**	8.85	7.66	-1.19	-
Southeastern	**Houston**	3	Cropland	**39**	6.17	13.71	7.54	31
Southeastern	**Houston**	4	Grassland	**32**	5.70	8.29	2.58	34
Southeastern	**Houston**	5	Forest to Grassland	**21**	16.60	11.89	-4.71	31
Southeastern	**Houston**	6	Cropland to Grassland	**42**	9.92	11.99	2.07	-
Southeastern	**Houston**	7	Cropland to Grassland	**28**	9.93	12.63	2.70	-
Southeastern	**Winona**	8	Forest	**33**	12.58	31.25	18.68	30
Southeastern	**Winona**	9	Cropland	**35**	3.25	7.67	4.43	31
Southeastern	**Winona**	10	Cropland	**28**	20.44	9.48	-10.96	31
Southeastern	**Winona**	11	Cropland	**35**	5.66	11.10	5.44	29
Southeastern	**Winona**	12	Cropland	**27**	7.86	17.34	9.48	29
Southeastern	**Winona**	13	Cropland to Forest	**53**	4.39	8.30	3.91	30