

# **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<sup>-1</sup> 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<sup>-1</sup> 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<sup>-1</sup> 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<sup>-1</sup> 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<sup>-1</sup> 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.

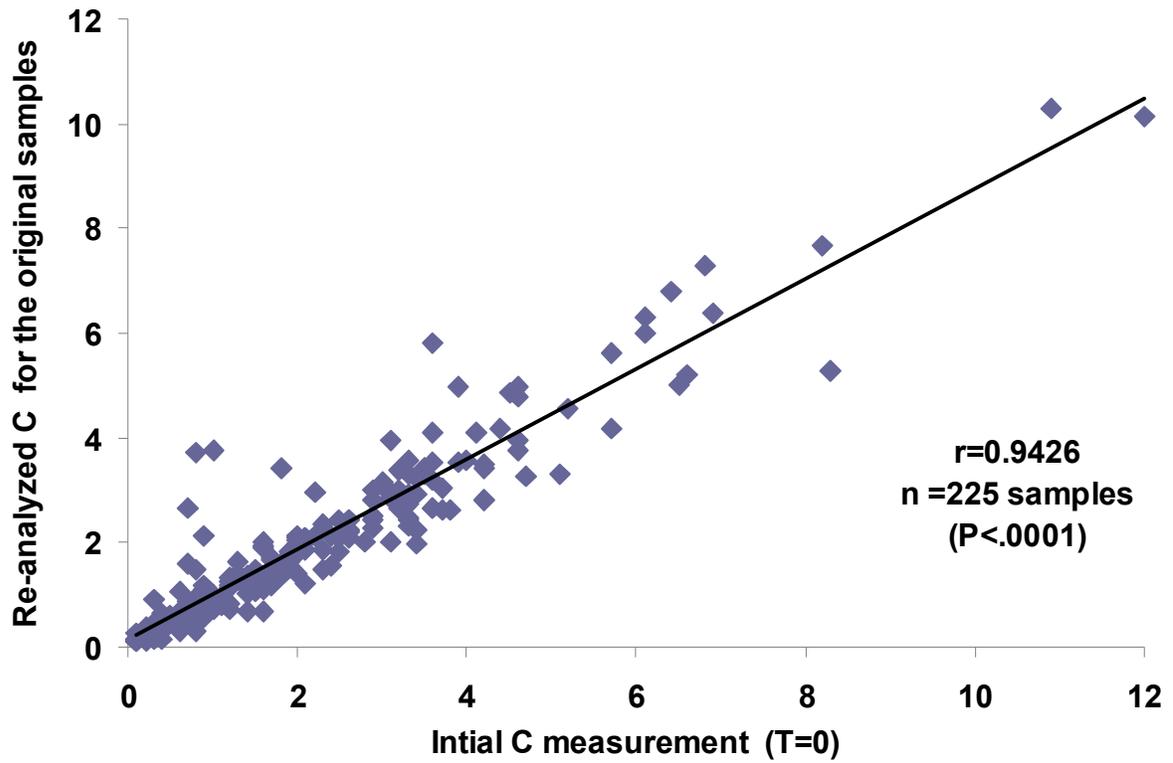
**Table 1. Detailed information for the sampled sites:**

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

<sup>†</sup> For proximity, we only sampled the sites from Itasca Co. that were close to St. Louis North Co.

<sup>‡</sup> For some of the sites, permission was obtained by email contact.

<sup>‡</sup> 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 <sup>-1</sup> soil .....				yrs	inches
Forest	13.4	18.5	5.1 ( <i>P</i> =0.0068)	24	30	24
Cropland	16.9	14.6	- 2.3 ( <i>P</i> =0.0280)	51	31	27
Grassland	10.5	15.7	5.2 ( <i>P</i> =0.1330)	9	30	30

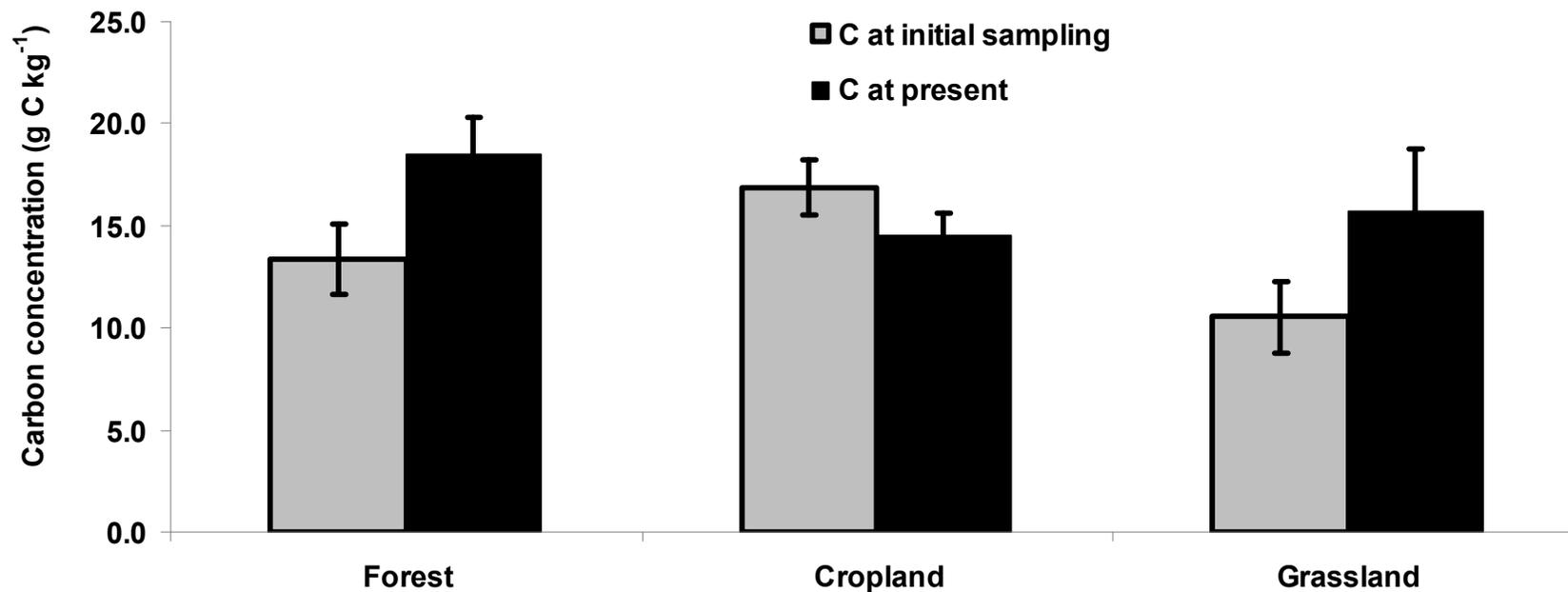


Figure 2. Changes in carbon concentrations after 30 years for sites that remained in the same management.

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

	Forest <sup>1</sup>			Grassland <sup>2</sup>			Cropland <sup>3</sup>		
Horizon	1	2	3	1	2	3	1	2	3
Initial C (g C kg <sup>-1</sup> 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 <sup>-1</sup> 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 <sup>-1</sup> 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

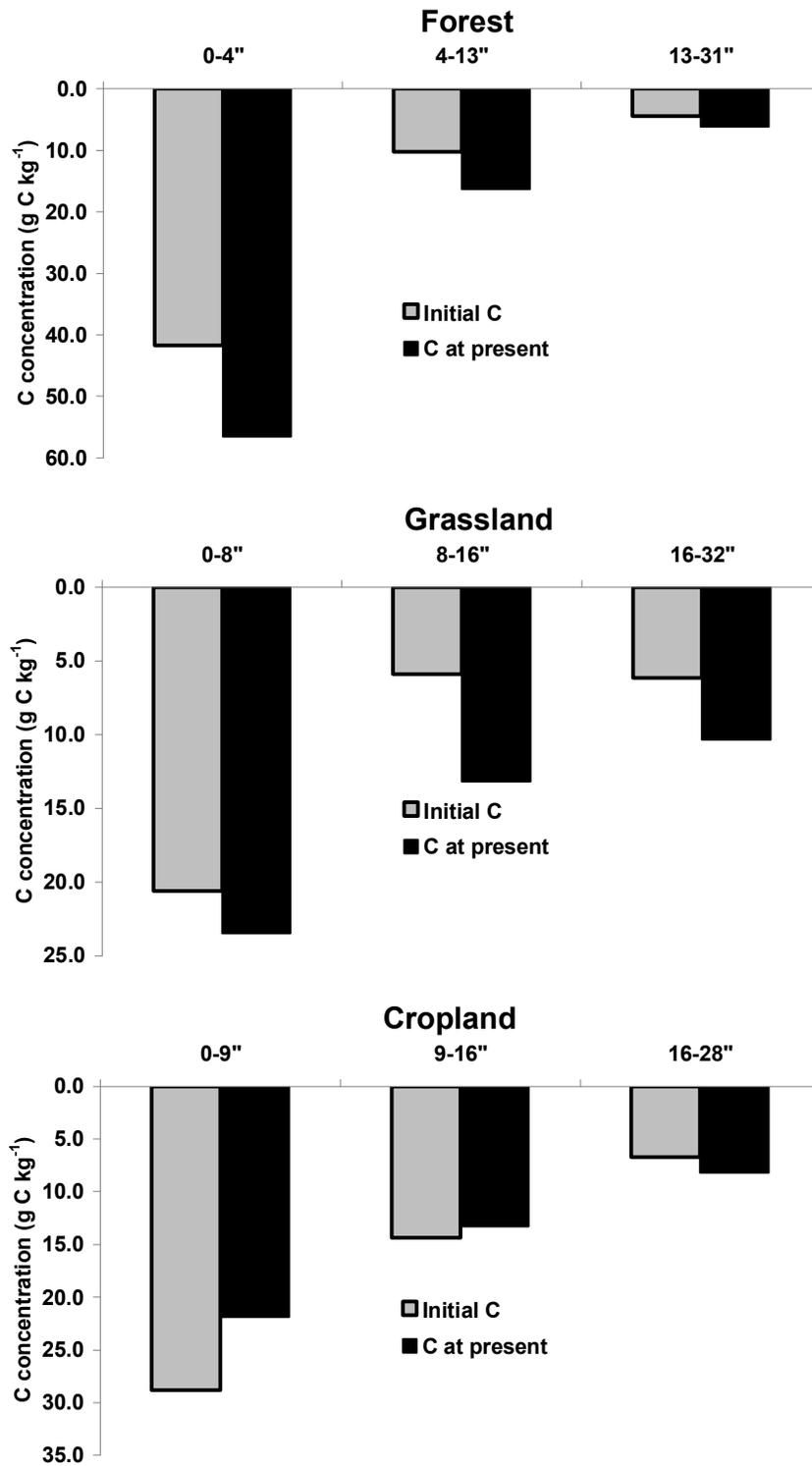
\* Indicates significant differences at  $P < 0.05$

\*\* 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 <sup>-1</sup> soil .....				yrs	inches
Forest to Grassland	13.6	14.1	0.5 ( <i>P</i> =0.8787)	3	30	29
Cropland to Forest	4.5	13.2	8.7 ( <i>P</i> =0.0753)	3	31	33
Cropland to Grassland	12.2	18.8	6.5 ( <i>P</i> =0.0299)	12	30	27

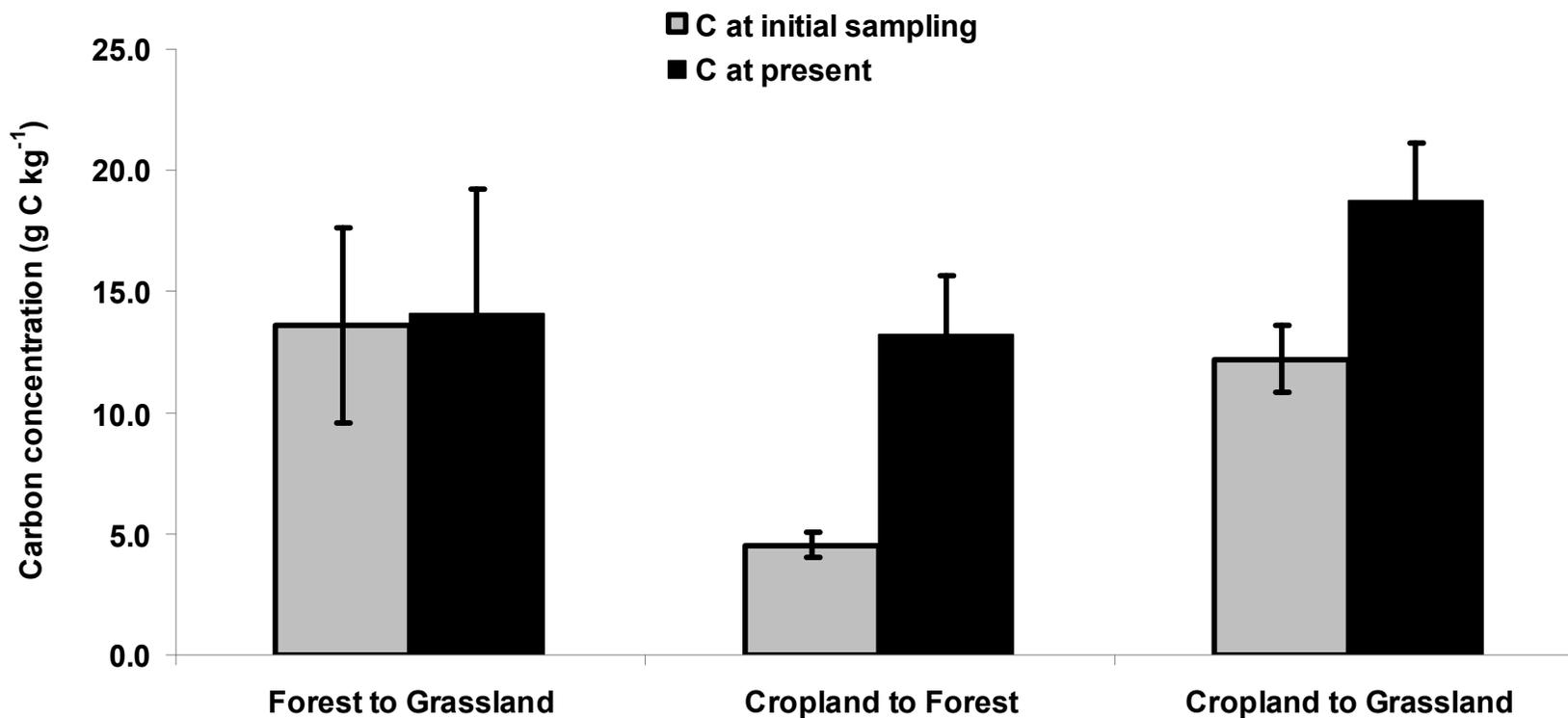


Figure 4. Changes in carbon concentration after 30 years at sites that changed management.

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

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

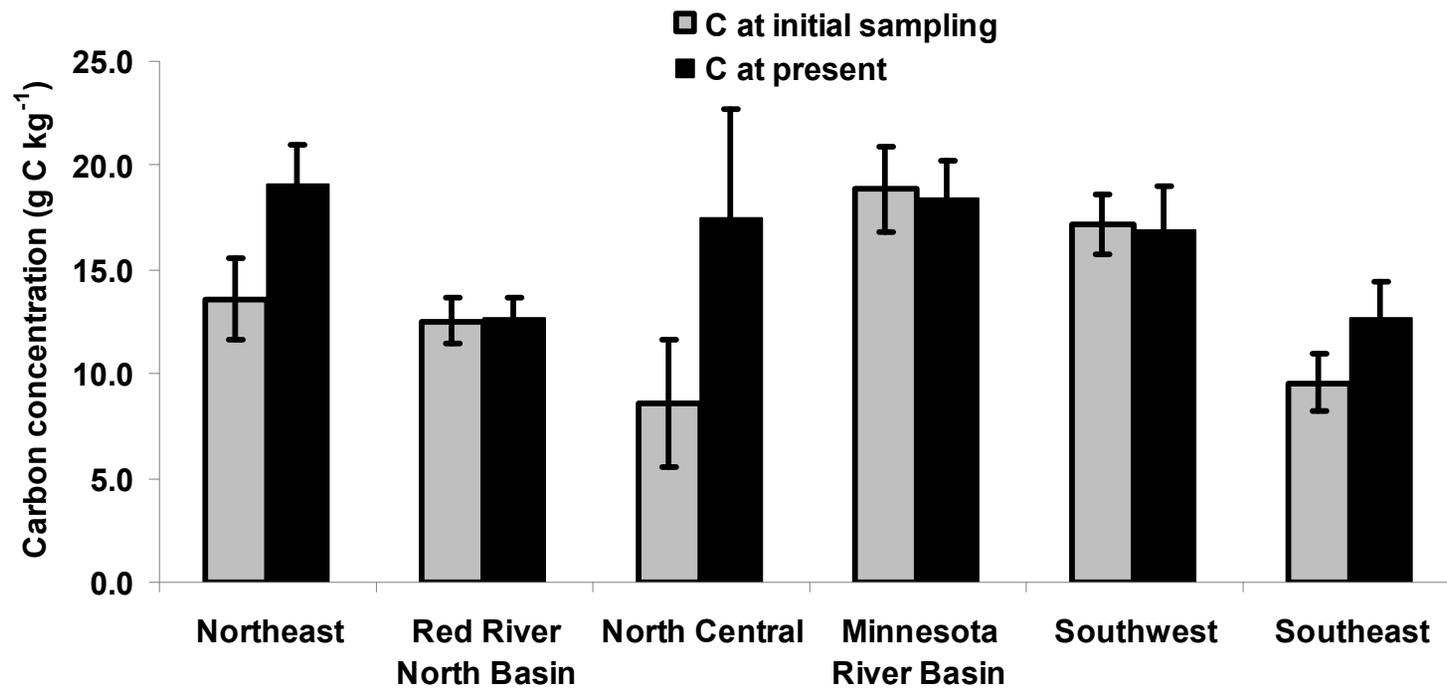


Figure 5. Average changes in carbon concentration in 6 different regions of Minnesota after 30 yrs.

# 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 <sup>-1</sup> 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 <sup>-1</sup> 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 <sup>-1</sup> 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