A Report on the Southwest North Dakota Soil Health Demonstration Project Site 2008-2016

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Abstract

A soil health demonstration project was initiated in western North Dakota in 2008 to improve the soil health awareness and knowledge of area producers. Several soil health parameters were measured during the demonstration that indicate that soil health had improved significantly by 2016, particularly water infiltration and nitrogen availability for crop production.

Introduction

The SW ND Soil Health Demonstration Project, located on the NE ¼ of Section 24, Township 143 North, Range 96 West in Dunn County, ND, approximately two miles south of Manning, ND (see Figure 1) was a joint project of the Dakota West Resource Conservation and Development Council, Dunn County Soil Conservation District, Western and Central Stark County Soil Conservation District, United States Department of Agriculture Natural Resources Conservation Service, Dickinson State University and North Dakota State University Dickinson Research and Extension Center. The demonstration project was conducted with funding from a United States Department of Agriculture Sustainable Agriculture Research & Education (SARE) grant from 2008 through 2012. Objectives of the demonstration project were to improve awareness and knowledge of soil health among producers and resource professionals in southwestern North Dakota, motivate producers to implement practices on their own operations that would improve soil health, and demonstrate a cropping system utilizing no-till and cover crops to improve soil health. Soil health is defined as the continued capacity of soil to function, particularly in the areas important to crop production and environmental protection, such as water infiltration and plant nutrient cycling.

Materials and Methods

A diverse crop rotation of three years of alfalfa, winter triticale/hairy vetch, corn, oats/peas, a multi-species cover crop, spring wheat, and winter wheat, was implemented during the study on all eight fields. Planting was accomplished with a John Deere 1590 disc-opener no-till drill. All crops received commercial fertilizer when recommended by annual soil test reports (see Table 2). The multi-species cover crop included up to 10 species of warm and cool season grasses, legumes and brassicas. From 2012 through 2016, the demonstration project fields continued to be planted without tillage and fertilized according to soil test recommendations though the crop rotation was modified slightly to adjust for weather conditions (see Table 3 in Appendix). This project was designed and executed for demonstration and education purposes and not as replicated research; the results are provided as observed without a control to serve as a standard for comparison. However, the results illustrate positive changes in soil health that suggest that further study would be worthwhile.

Sampling sites were located in each field and samples analyzed for Nitrogen, Phosphorous, Potassium, pH, soluble salts, and organic matter by a commercial laboratory. Water infiltration tests for an initial and second inch of water, were conducted in 2008 on fields 1 and 4, on all fields in 2011, and again in 2016 utilizing a single 6-inch tall by 6-inch diameter metal ring driven four to five inches into the soil. An inch of water was applied inside the ring and water infiltration into the soil timed and recorded. The procedure was then repeated with a second inch of water. This procedure was conducted in three locations within each field to achieve an average infiltration rate for the field.

Soil samples for biological analysis were collected from 0 – 3” in 2008, 2011 and 2016. Samples were sent to Earthfort™ in Corvallis, OR for analysis that included: active bacteria, total bacteria, active fungi, total fungi, fungal hyphal diameter, flagellate protozoa, amoebate protozoa, ciliate protozoa, total nematodes, nematode species (bacterial, fungal, fungal/root and root feeding) and potential nitrogen cycling capacity.

Results

The most dramatic positive changes in soil health on the site from 2008 to 2016 were the increase in the rate of water infiltration into the soil and the increase in plant nutrient cycling expressed as biologically generated plant available nitrogen. See Table 1 below for changes in each parameter measured over the 2008 to 2016 demonstration time period.

Other notable changes were a slight increase in soil pH, a slight decrease in soil salinity (Electrical Conductivity), a slight increase in soil organic matter and significant increase in the number of protozoa and the number and diversity of nematodes.

Table 1: Net change of soil properties from first measurement to 2016 measurement.

2008 or 2011 Benchmark	2016	Net Change	Percent Change	Soil Property 0”-6” depth
2.5	44.8	42.3	1699%	Water infiltration first inch (in/hr.)*
1.3	10.2	8.9	685%	Water infiltration second inch (in/hr.)*
32.5	21.5	-11.0	-34%	Nitrate (ppm) 0 - 24"
49.1	21.3	-27.8	-57%	Phosphorous (ppm)
364.4	252.1	-112.3	-31%	Potassium (ppm)
6.9	7.0	0.1	1%	pH
0.6	0.3	-0.3	-52%	Electrical Conductivity (dS/m)
2.7	3.0	0.3	11%	Organic Matter (%)
28.4	7.9	-20.5	-72%	Active Bacteria (µgr/gr)
904.1	981.7	77.6	9%	Total Bacteria (µgr/gr)
4.8	3.5	-1.3	-27%	Active Fungal (µgr/gr)
179.8	170.6	-9.2	-5%	Total Fungal (µgr/gr)
2.9	2.9	0.0	0%	Hyphal Diameter (µm)
5,670.1	4,489.0	-1,181.1	-21%	Flagellate Protozoa (no/gr)
11,489.1	404,703.2	393,214.1	3422%	Amoebate Protozoa (no/gr)
58.1	135.6	77.5	133%	Ciliate Protozoa (no/gr)
6.2	13.4	7.2	116%	Total Nematodes (no./gr)
4.4	6.3	1.9	43%	Species of Bacterial Feeding Nematodes (no.)
2.4	4.2	1.8	75%	Species of Fungal Feeding Nematodes (no.)
2.9	2.9	0.0	0%	Species of Fungal/Root Feeding Nematodes (no.)
1.8	0.7	-1.1	-61%	Species of Root Feeding Nematodes (no.)
100.0	275.0	175.0	175%	Plant available N supply (lbs./ac.)

*Water infiltration benchmark measurements on Fields 1 & 4 were made in 2008, other fields in 2011.

Table 2: Crop yields and Fertilizer Applied

Soil Health Demonstration Field 2408

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Alfalfa	Mowed	5.5	26	0
2009	Alfalfa	2.56 ton	0	15	15
2010	Alfalfa	3.2 ton	0	15	15
2011	Winter Triticale/Hairy Vetch	3.8 ton	42	10	0
2012	Corn	3.97 bu	70	15	10
2013	Oat/Pea	2.13 ton	0	0	0
2014	Spring Wheat*	8.5 bu	142	15	10
2015	Winter Wheat	2.34 ton	0	0	0
2016	Corn	92 bu	0	0	0
2017	Barley/Pea	-	0	0	0

Soil Health Demonstration Field 2401

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Multi-Specie Cover Crop	no harvest	5.5	26	0
2009	Alfalfa-Swtclvr-Turnip	-	0	15	15
2010	Alfalfa	2.85 ton	15	29.7	80.6
2011	Winter Triticale/Hairy Vetch	3.19 ton	15	15	0
2012	Spring Triticale/Hairy Vetch	1.33 ton	21	15	10
2013	Corn	93.2 bu	35	15	10
2014	Pea/Oat	2.38 ton	0	0	0
2015	Spring Wheat	44 bu	0	0	0
2016	Winter Wheat	61 bu	0	0	0
2017	Alfalfa	-	0	0	0

Soil Health Demonstration Field 2407

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Alfalfa	Mowed	5.5	26	0
2009	Alfalfa	2.04 ton	0	15	15
2010	Winter Triticale/Hairy Vetch	3.9 ton	127	39	21
2011	Corn	58 bu	23	15	10
2012	Oat/Pea	2.45 ton	0	0	0
2013	Spring Wheat	67 bu	6	25	0
2014	Winter Triticale/Hairy Vetch	1.94 ton	12	40	0
2015	Alfalfa	2.03 ton	0	0	0
2016	Winter Triticale/Hairy Vetch	3.63 ton	12	40	0
2017	Barley	-	0	0	0

Soil Health Demonstration Field 2402

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Spring Wheat	9 bu	5.5	26	0
2009	Winter Wheat	56.9 bu	5.5	26	0
2010	Alfalfa	.86 ton	8.7	22.5	33
2011	Alfalfa	3.61 ton	0	15	15
2012	Alfalfa	1.01 ton	0	15	16
2013	Triticale	3.01 ton	12	40	0
2014	Corn	41.3 bu	110	17	10
2015	Oat/Pea	2.33 ton	0	0	0
2016	Barley/Pea/Winter Triticale/Hairy Vetch	1.32 ton	0	0	0
2017	Winter Triticale/Hairy Vetch	-	0	0	0

Soil Health Demonstration Field 2406

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Spring Wheat	9.3 bu			
2009	Winter Triticale/Hairy Vetch	3.75 ton	5.5	26	0
2010	Corn	30 bu	47	36	26
2011	Oat/Pea	2.14 ton	0	0	0
2012	Spring Wheat	43.46 bu	47	15	10
2013	Winter Wheat	58 bu	145	0	15
2014	Sanfoin	1.38 ton	0	0	0
2015	Sanfoin	4.01 ton	0	0	0
2016	Winter Triticale/Hairy Vetch	1.90 ton	12	40	0
2017	Multi-Specie Cover Crop	-	0	0	0

Soil Health Demonstration Field 2403

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Field Pea	20.6 bu	5.5	26	0
2009	Spring Wheat	40.9 bu	10	15	10
2010	Winter Wheat	56.4 bu	67	15	10
2011	Alfalfa	2.8 ton	0	15	15
2012	Alfalfa	0.79 ton	0	16	15
2013	Alfalfa	3.59 ton	146	25	10
2014	Winter Triticale/Hairy Vetch	3.16 ton	62	16	10
2015	Corn	88 bu	0	23	0
2016	Barley/Pea/WTHV	1.98 ton	0	0	0
2017	Winter Triticale/Hairy Vetch	-	0	0	0

Soil Health Demonstration Field 2405

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Barley	1.3 ton	5.5	26	0
2009	Corn	46 bu	31	16	10
2010	Pea/Oat	2.15 ton	0	0	0
2011	Spring Wheat	29 bu	111	15	10
2012	Winter Wheat	54.3 bu	122	15	10
2013	Sanfoin	1.81 ton	0	0	0
2014	Barley	1.05 ton	0	0	0
2015	Alfalfa	3.22 ton	0	0	0
2016	Alfalfa**	0.32 ton	0	0	0
2017	Corn	-	0	0	0

Soil Health Demonstration Field 2404

Year	Crop	Yield/ac.	N applied lbs/ac	P_2O_5 applied lb/ac	K_2O applied lb/ac
2008	Corn	.7 ton	5.5	26	0
2009	Pea/Oat	3.16 ton	0	0	0
2010	Spring Wheat	47 bu	46	15	10
2011	Winter Wheat	42 bu	86	15	10
2012	Alfalfa	0.59 ton	0	0	0
2013	Alfalfa	3.89 ton	0	0	0
2014	Alfalfa	3.58 ton	0	0	0
2015	Triticale	2.86 ton	12	40	0
2016	Winter Triticale/Hairy Vetch	3.36 ton	0	0	0
2017	Corn	-	0	0	0

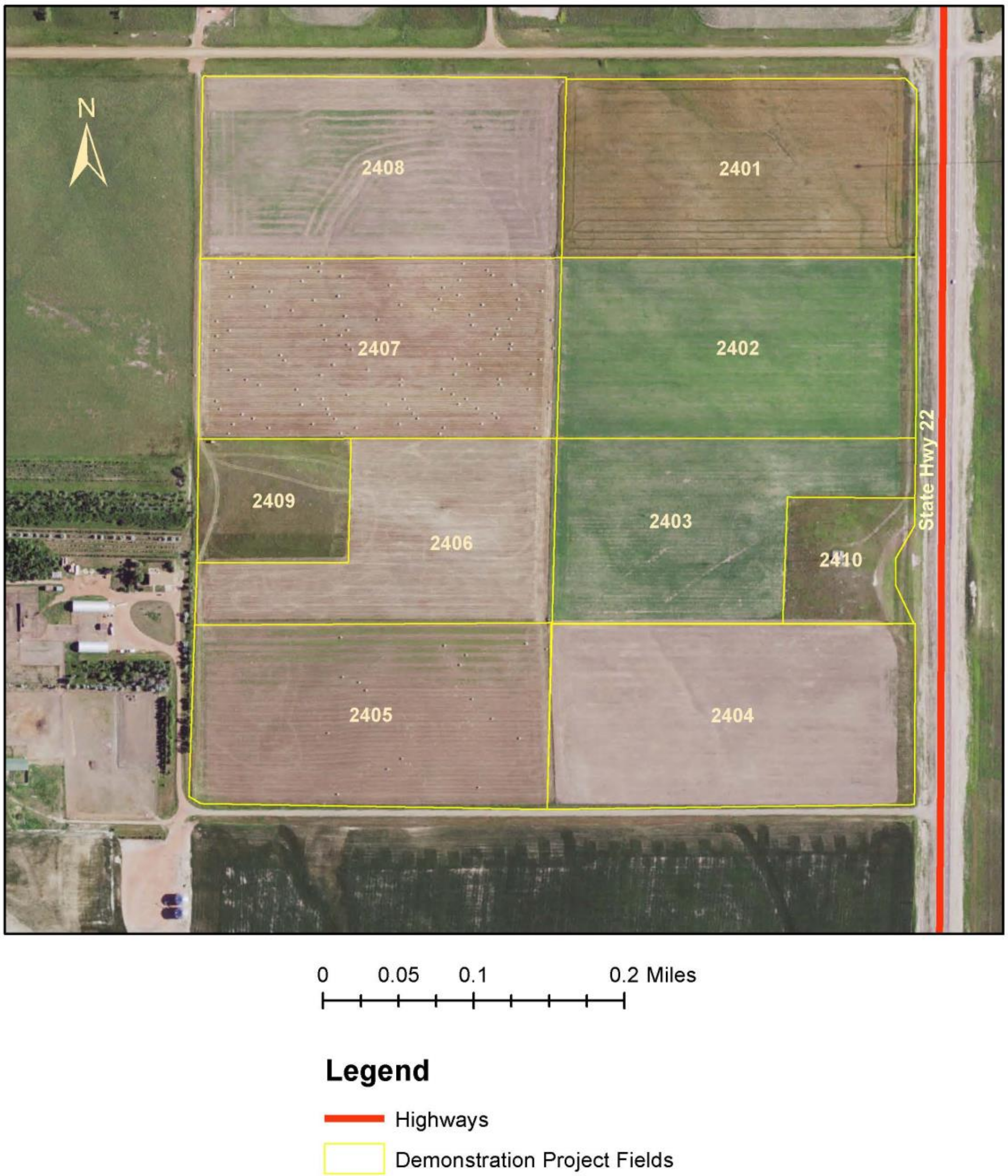
* Hail damaged

** Insect damaged

Yields shown in bushels are for seed, yields shown in tons are for forage harvested as hay or grazed.

2017 Crop was not yet harvested at the time of report

Figure 1: Southwest North Dakota Soil Health Demonstration Project Site
NE 1/4 Section 24 T143N R96W, Dunn County, ND



NAD 1983 StatePlane ND South
Projection: Lambert Conformal Conic
Jon Stika 2017

Water runs off of field 2408 on June 2, 2008 after .3” of rain over the course of the day. In 2016, water infiltration on field 2408 was 2.5” per hour.

Discussion

Water infiltration into the soil controls the water that is available for plant growth. Water that does not infiltrate the soil either runs off of the field or ponds and evaporates. Water that runs off of the field is no longer available for crop production and may cause soil erosion. During water infiltration testing, the first inch of water that infiltrates into the soil is greatly influenced by soil moisture at the time that the measurement is conducted. Once the soil is moistened by the first inch of applied water, the second inch of water infiltration better illustrates the stability of soil aggregates and pores to continue to allow water to enter the soil. The observed increase in water infiltration of nearly nine inches per hour on the demonstration fields over the eight years of the project suggests that managing with the intent of creating favorable habitat for soil microorganisms can lead to an increase in the biological glues that stabilize soil aggregates and soil pores. Water infiltrating into the soil is critical for both plants and soil microorganisms’ growth and productivity.

The decrease in nitrate nitrogen, phosphorous and potassium shown by conventional soil testing methods seems to contradict the increase in plant available nitrogen supply shown by the Earthfort™ biological soil analysis. However, it should be noted that conventional soil testing is based upon chemical extraction of measured nutrients from the soil and the corresponding fertilizer recommendations are based on how soils that experience regular tillage react to the addition of fertilizers. Since the soils in the demonstration project fields were not tilled for eight years, the soil environment and biology changed significantly. As soil health improved, more of the nitrogen and other crop nutrients in the soil were present in biological forms rather than ionic (chemical) forms and thus less prone to loss by leaching or volatilization; but less measureable by standard soil testing methods.

The soil nitrogen cycling potential provided by Earthfort™ analyses is based on the populations and balance of predators (primarily protozoa and nematodes) to prey (primarily bacteria and fungi). When bacteria and fungi are consumed by protozoa and nematodes the excess nitrogen that occurs is excreted into the soil by the predators. With a moderate increase in total bacteria, a slight decrease in total fungi, a significant increase in the number of protozoa, and increases in the number and diversity of nematodes in the soil, both predators and prey are currently sufficient in the demonstration field soils to produce a high rate of nitrogen cycling. The average nitrogen cycling potential across all eight fields of the demonstration project in 2016 was 275 pounds/acre/year of plant available nitrogen. A typical spring wheat crop of 40 bushels/acre in western North Dakota will need approximately 120 pounds of actual nitrogen. Nitrogen supplied by soil microorganisms in aerobic healthy soil is rarely subject to leaching into water or volatilization into the air. This increased nitrogen cycling potential suggests that commercial nitrogen fertilizer may no longer be needed to supply the nitrogen needs of crops grown in the demonstration project fields.

The slight increase in soil pH observed during the period of the demonstration project is the opposite of what is typically observed in cropland soils of the Great Plains where soil pH has been declining due to the continued use of ammonium based nitrogen fertilizer (Schroder et. Al. 2011). Maintaining soil pH near neutral (7.0) is important for nutrient availability and uptake by crops.

The slight decrease in measured soil salinity may be the result of increased water infiltration leaching soluble salts deeper into the soil. Soil salinity was not measured below six inches. This trend of reduced soil salinity may decrease more rapidly if the use of commercial fertilizer (most of which are salts) is reduced or suspended. Soil salinity is a major issue in many agricultural soils in North Dakota. A reduction in soil salinity by improving soil health and water infiltration into the soil would benefit producers where salinity is a limitation to crop production.

The slight increase in soil organic matter is encouraging and suggests that continued management of the soil as a biological system should result in a continued increase in soil microorganisms and their aggregate-stabilizing byproducts that retain carbon in the soil. Soil organic matter may increase at a greater rate if crops grown for forage are fed to livestock on the fields where the forage originates instead of being exported from the field and fed elsewhere. Carbon retained in the soil benefits many soil functions and reduces the amount of carbon dioxide in the atmosphere.

Protozoa are predators of bacteria in the soil. Among protozoa, flagellates are the relatively smaller species, followed by amoebae, with ciliates being the largest. Flagellate and amoebate protozoa typically range in number from 10,000 to 100,000 per gram of soil. Ciliates typically occur at 0 to 200 per gram of soil. 2016 soil analysis showed an average of 4,489 flagellate protozoa, 404,703 amoebate protozoa, and 136 ciliate protozoa per gram of soil. Thus, the flagellate protozoa were somewhat below the expected range, amoebate protozoa significantly above the expected range, and ciliate protozoa within the expected range. The high populations of protozoa, combined with the high populations of bacteria (average of 982 µgr/gram soil with an expected range of 300 – 600 µgr/gram soil) sets the stage for the exceptional nitrogen cycling mentioned previously. The more nitrogen that is captured from the atmosphere and cycled through the soil biologically, the less nitrogen fertilizer will be needed to support crop yields at a significant cost savings to producers.

Nematodes also serve as predators in the soil; consuming bacteria, fungi, plant roots and other nematodes. The
7.2 increase in nematode populations per gram of soil over the demonstration project period also contributes to increased nitrogen cycling. The diversity of bacterial and fungal feeding nematodes increased, while the diversity of fungal/root feeding nematodes remained the same, and the species of nematodes that feed exclusively on plant roots decreased by 1.1 species. This bodes well for both nitrogen cycling and reduced predation of plant roots by nematodes. Again, this can reduce the cost of nitrogen fertilizer inputs to achieve desired crop yields.

Conclusions

The positive changes noted in several critical soil health parameters of water infiltration, nitrogen cycling, pH, salinity, and organic matter over the life of the soil health demonstration project is very encouraging and suggests areas for further scientific study. Water infiltration into the soil is critically important for crop production in western North Dakota where precipitation is often limited during the growing season. Water that infiltrates into the soil also does not contribute to soil erosion and offsite surface water impairment. Nitrogen captured from the atmosphere and cycled through the soil biologically provides this vital nutrient to crops as they need it and can significantly reduce the need for purchased nitrogen inputs. Soil pH is important to nutrient availability to crops. Soil that is buffered biologically can maintain a favorable pH for crop production. Increased water infiltration not only provides water for crop production, but helps move salts deeper into the soil where they are less detrimental to the establishment of crop seedlings. Organic matter is at the heart of soil health and increases in both quantity and quality to improve all aspects of soil function. Soil organic matter has declined significantly from the levels originally found in soils across North Dakota prior to settlement and the plow. Restoring soil organic matter is a major indicator of restoring soil health. The adoption of management that improves soil health based on the principles of (1) less soil disturbance, (2) increased plant species diversity, (3) maintaining living roots in the soil as much time as possible, and (4) keeping the soil covered at all times, (Stika 2016) can improve soil health in all parts of North Dakota (and the nation) as evidenced by what was observed on the southwest North Dakota soil health demonstration fields.

References

Schroder, J.L., H. Zhang, K Girma, W. Raun, C. Penn and M. Payton. 2011. Soil Acidification from Long-Term Use of Nitrogen Fertilizers on Winter Wheat. Soil Sci. Soc. Am. J. 75:957–964.

Southwest North Dakota Soil Health Demonstration Project Final Report http://mysare.sare.org/sare_project/LNC09-312/?page=final

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Stika, J. A. (2016) *A Soil Owner's Manual: How To Restore And Maintain Soil Health.* Dickinson, ND: Stika.

Appendix

2008*	8.57	6.87	* Data from the NDAWN (North Dakota Agricultural Weather Network) site at the Dickinson Research and Extension Center in Dickinson, ND approximately 20 miles south of the Southwest North Dakota Soil Health Demonstration Project site. 2010 - 2017 data are from the SW Dunn NDAWN station approximately 12 miles northeast of the Southwest North Dakota Soil Health Demonstration Project site, or .5 mile southwest of Dunn Center, ND.
2009*	13.2	10.86	
2010	13.96	12.7	
2011	16.52	14.24	
2012	11.39	7.71	
2013	22.56	18.31	
2014	18.12	16.96	
2015	16.45	14.36	† May-July
2016	18.84	12.84	‡ January-July
2017	3.31‡	2.88†	Average Annual Precipitation for Dickinson, ND is 16"-17".