Sustainable Agroecosystem for Soil Health in the Northern Great Plains (Williston, ND - 2018)

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This long-term dryland research project was initiated in 2013 with the objectives of developing agricultural systems that improve soil health, crop production, precipitation use, and economic sustainability of no-till dryland farming systems in the Northern Great Plains of the USA. In this project, there are five fixed and six dynamic rotations. Every year, each phase of every fixed rotation has been included. The experimental design is randomized complete block with four replications. The plot size is 60 ft. x 200 ft.

Experimental Details

- Treatments:
  - 5 Fixed Rotations and 6 “Dynamic” Rotations.
  - Each phase of every rotation included each year (fixed rotations).
- Field Design:
  - Randomized Complete Block; 4 Replications.
  - Individual plots are 60 by 200 feet. Total area (including roadways and borders) is 40 acres.
- All plots are No-Till.

The 5 Fixed Rotations

2013	2014	2015	2016	2017	2018
Durum	Fallow	Durum	Fallow	Durum	Fallow
Durum	Durum	Durum	Durum	Durum	Durum
Durum	BP1*	Pea	Corn	Safflower	Durum
Durum	WW/ BP2	Pea/BP3	Corn	Safflower	Durum
………………………………...Perennial Grass Mix with Pollinator…………………………..					

* BP1 = Biological primer 1; BP2 = Biological Primer 2; BP3 = Biological Primer 3; WW = Winter Wheat.

What are the Biological Primers?

- Biological Primer 1 (BP1) is a full season cover crop mix, seeded between June 1st and June 20th.
  Pearl millet (3.5)†, Sorghum × Sudan (3.5), Turnip (1.0), Radish (2.0), Berseem clover (1.0), Sunflower (2.0), Soybean (15.0), Cowpea (10.0), Flax (1.0), Hairy vetch (3.0), Mammoth red clover (1.0), Phacelia (2.0), and Italian ryegrass (3.0).
- Biological Primer 2 (BP2) is a cover crop mix seeded after winter wheat but before August 10th.
  Turnip (1.0), Radish (2.0), Kale (1.0) Lentil (5.0), Oats (30.0), Sweet clover (1.0), and Buckwheat (2.0).
- Biological Primer 3 (BP3) is a cover crop mix seeded after pea.
  Triticale (40.0), Hairy vetch (2.0), Common alfalfa (2.0), Mammoth red clover (2.0), Turnip (1.0), and Radish (2.0).

†The numbers in brackets are the seeding rates in lb/a.

"Dynamic" Rotations

- Crops in the dynamic rotations will be determined each year based on weather and market conditions and using the following tools:
  - The USDA-ARS Crop Sequence Calculator (An interactive program for viewing crop sequencing information and calculating returns; www.mandan.ars.usda.gov)
  - The NDSU Projected Crop Budgets for Northwest North Dakota (www.ag.ndsu.edu/publications/farm-economics-management).
- The crops will include a mix of cool-and warm-season grasses and broadleaves.
- Each year durum will be grown in one of the rotations to serve as a comparison.

The Dynamic Rotations

2013	2014	2015	2016	2017	2018
Durum	WW*	Lentil	WW	Chickpea	Durum
Corn	Soybean	Durum	Corn	Soybean	HRSW
Soybean	Sunflower	Barley	Pea	WW	Flax
Safflower	Barley	Pea	Durum	Lentil	WW
Sunflower	HRSW	WW	Lentil	Durum	Sunflower
Pea	Durum	Safflower	Barley	HRSW	Lentil

* SW = Spring Wheat; WW = Winter Wheat.

Measurements

- Crop Performance: leaf chlorophyll, canopy temperature, grain yield, protein or oil content, grain nitrogen and phosphorus, total dry matter, above ground biomass production, carbon and nitrogen ratio of above ground biomass, crop water use.
- Soil Quality: infiltration; aggregate stability; bulk density; organic matter amount, plant-available levels of nitrogen, phosphorus, potassium and other nutrients; pH; salinity.
- Diseases: tan spot, stripe rust, wheat streak mosaic virus and Fusarium head blight in durum.
- Soil microbial parameters: Microbial Biomass Carbon, Potential Carbon Mineralization, Neutral Lipid Fatty Acid analysis (NLFA) to measure beneficial fungi.

Results

Yield, Quality, and Economic Returns from Cash Crops Under Different Crop Rotations

There was a significant effect of treatment (crop rotation) on yield and test weight of durum and winter wheat. The durum yield from Treatment 2 (Durum-Fallow-Durum-Fallow-Durum; 56 bu/a) was statistically on par to the yield from Treatments 3 (Durum-Durum-Durum-Durum-Durum) and 14 (WW-Lentil-WW-Chickpea-Durum), but had 5–11 bushels more yield than from Treatments 4 (BP1-Pea-Corn-Safflower-Durum) and 9 (WW/BP2-Pea/BP3-Corn-Safflower-Durum) (Fig. 1A). The higher durum yield from Treatment 2 was due to Fallow in the previous year; and was consistent to the earlier year's results. The test weight of durum from Treatment 2, 3, and 14 was about 58.7 lb/bu, which was 3 lb/bu higher than from Treatment 4 and 9 (Fig 1B). The winter wheat yield from Treatment 17 (Barley-Pea-Durum-Lentil-WW; 49 bu/a) was 17 bushels higher than from Treatment 10 (Pea/BP3-Corn-Safflower-Durum-WW/BP2) (Fig 2A); and the test weight from Treatment 17 (61.5 lb/bu) was 2.3 lb/bu higher than from Treatment 10.

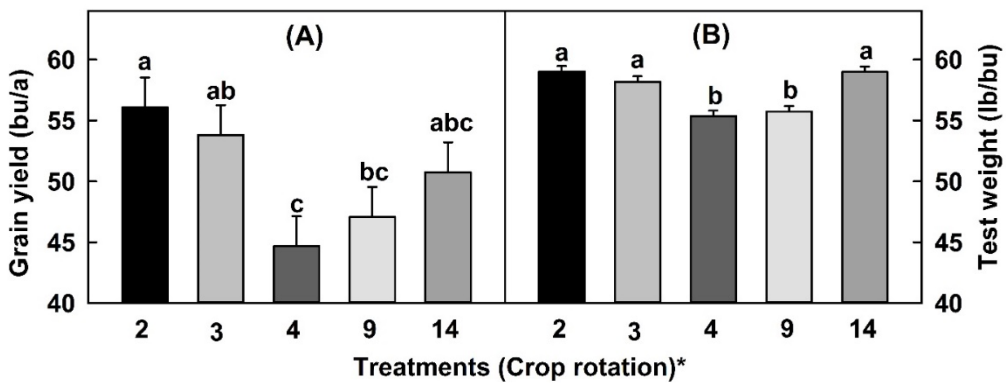

Figure 1. Yield and test weight of durum under different treatments.

*Crop rotations: 2 = Durum-Fallow-Durum-Fallow-Durum; 3 = Durum-Durum-Durum-Durum-Durum; 4 = BP1-Pea-Corn-Safflower-Durum; 9 = WW/BP2-Pea/BP3-Corn-Safflower-Durum; 14 = WW-Lentil-WW-Chickpea-Durum.

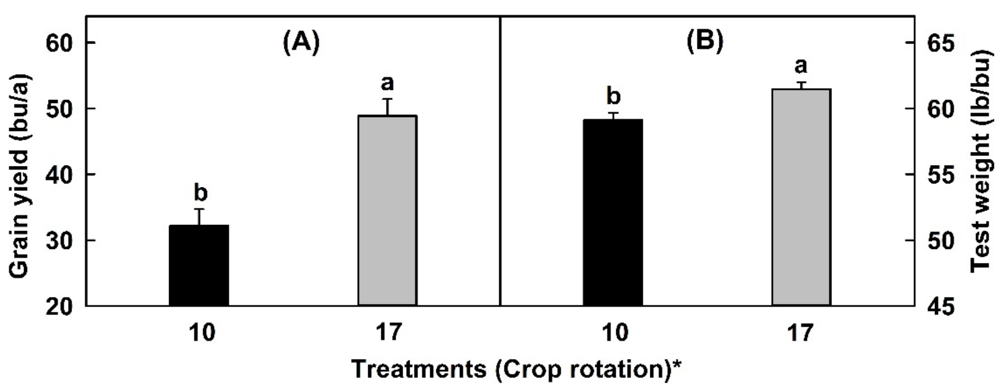

Figure 2. Yield and test weight of winter wheat under different treatments.

*Crop rotations: 10 = Pea/BP3-Corn-Safflower-Durum-WW/BP2; 17 = Barley-Pea-Durum-Lentil-WW.

The effect of crop rotation was not evident on the grain yield of other cash crops. Pea yield, averaged across the Treatments 6 (Corn-Safflower-Durum-BP1-Pea) and 11 (Corn Safflower-Durum-WW/BP2-Pea/BP3), was 45 bu/a; corn yield, averaged across the Treatments 7 (Safflower-Durum-BP1-Pea-Corn) and 12 (Safflower-Durum-WW/BP2-Pea/BP3-Corn), was 71 bu/a; and safflower yield, averaged across the Treatments 8 (Durum-BP1-Pea-Corn-Safflower) and 13 (Durum-WW/BP2-Pea/BP3-Corn-Safflower), was 1618 lb/a.

The grain yield of other cash crops were as follows: sunflower yield from Treatment 18 (HRSW-WW-Lentil-Durum-Sunflower) was 2232 lb/a; lentil yield from Treatment 19 (Durum-Safflower-Barley-HRSW-Lentil) was 1838 lb/a; hard red spring wheat yield from Treatment 15 (Soybean-Durum-Corn-Soybean-HRSW) was 31 bu/a; and flax yield from Treatment 16 (Sunflower-Barley-Pea-WW-Flax) was 31 bu/a.

This year, the biological primer BP2 from Treatment 10 (Pea/BP3-Corn-Safflower-Durum-WW/BP2), and biological primer BP3 from Treatment 11 (Corn-Safflower-Durum-WW/BP2-Pea/BP3) did not produce biomass. The biomass yield of the biological primer (BP1) from Treatment 5 (Pea-Corn-Safflower-Durum-BP1) was 4939 lb/a, and that of perennial mix from Treatment 20 (PM-PM-PM-PM-PM) was 1841 lb/a.

Table 1 shows the economic returns from cash crops in 2014, 2015, 2016, 2017, and 2018 under different crop rotations, and the average net return from each Treatment (crop rotation). The information is a report of observed results and is not intended to be used by producers in making financial decisions.

Table 1. The Economic Returns from Different Crop Rotations.

Rotations		Treatments	2014		2015		2016		2017		2018					
			Crop	Net Return*	Crop	Net Return*	Crop	Net Return*	Crop	Net Return*	Crop	Yield	Price†	Revenue	Direct Cost‡	Net Return*
#	Type	#		($/a)		($/a)		($/a)		($/a)		(bu or lb/a)	($/bu or lb)	($/a)	($/a)	($/a)
I**	Fixed	1	Fallow	-24.58	Durum	125.35	Fallow	-23.35	Durum	52.49	Fallow	0.00	0.00	0.00	23.35	-23.35
	Fixed	2	Durum	255.15	Fallow	-23.09	Durum	176.82	Fallow	-23.49	Durum	56.07	4.75	266.33	139.67	126.66
II	Fixed	3	Durum	202.15	Durum	64.28	Durum	150.13	Durum	57.55	Durum	53.80	4.75	255.55	139.67	115.88
III	Fixed	4	BP1	42.28	Pea	68.62	Corn	-10.81	Safflower	27.51	Durum	44.68	4.75	212.23	139.67	72.56
	Fixed	5	Pea	175.16	Corn	-36.61	Safflower	116.88	Durum	18.91	BP1	4938.95	0.03	133.35	57.37	75.98
	Fixed	6	Corn	30.21	Safflower	-6.08	Durum	121.66	BP1	107.06	Pea	43.71	5.00	218.55	143.28	75.27
	Fixed	7	Safflower	54.89	Durum	8.54	BP1	33.79	Pea	72.36	Corn	74.56	2.89	215.48	219.67	-4.19
	Fixed	8	Durum	145.15	BP1	90.00	Pea	37.34	Corn	-123.75	Safflower	1583.72	0.18	285.07	125.76	159.31
IV	Fixed	9	WW/BP2	64.57	Pea/BP3	71.20	Corn	-14.72	Safflower	38.25	Durum	47.07	4.75	223.58	139.67	83.91
	Fixed	10	Pea/BP3	211.64	Corn	-58.70	Safflower	95.49	Durum	4.39	WW/BP2	32.16	3.91	125.75	140.28	-14.53
	Fixed	11	Corn	14.82	Safflower	-44.11	Durum	110.14	WW/BP2	-7.96	Pea/BP2	47.21	5.00	236.05	143.28	92.77
	Fixed	12	Safflower	42.82	Durum	-10.37	WW/BP2	-15.03	Pea/BP3	-39.01	Corn	67.20	2.89	194.21	219.67	-25.46
	Fixed	13	Durum	145.15	WW/BP2	-29.24	Pea/BP3	82.08	Corn	-119.26	Safflower	1652.28	0.18	297.41	125.76	171.65
V	Dynamic	14	WW	55.72	Lentil	496.99	WW	8.39	Chickpea	269.46	Durum	50.76	4.75	241.11	139.67	101.44
	Dynamic	15	Soybean	16.64	Durum	98.17	Corn	-13.30	Soybean	-59.71	SW	30.78	4.90	150.82	137.57	13.25
	Dynamic	16	Sunflower	121.10	Barley	7.55	Pea	87.28	WW	8.92	Flax	30.89	10.00	308.92	106.28	202.64
	Dynamic	17	Barley	108.56	Pea	88.12	Durum	171.13	Lentil	38.41	WW	48.87	3.91	191.08	140.28	50.80
	Dynamic	18	SW	-36.48	WW	-22.49	Lentil	490.85	Durum	48.11	Sunflower	2232.25	0.15	340.42	177.05	163.37
	Dynamic	19	Durum	226.15	Safflower	23.82	Barley	125.22	SW	48.73	Lentil	1838.15	0.13	238.96	157.62	81.34
VI	Fixed	20	Per. Mix	105.89	Per. Mix	-8.26	Per. Mix	85.15	Per. Mix	74.51	Per. Mix	1841.70	0.03	49.73	8.26	41.47

†The market prices were obtained from grain elevators in and around Williston on November 29, 2018. ‡The direct costs were calculated from the estimations given in the 'North Dakota 2018 Projected Crop Budgets - North West' by Andrew Swenson. *Net Return = Revenue - Direct cost. **This rotation has a Fallow component, therefore the durum yield was consistently high. ***BP1 = Biological Primer 1; BP2 = Bio. Primer 2, BP3 = Bio. Primer 3; Yield and economic return from BP2 and BP3 are not included. #Per=Perennial; in 2013, 2014, and 2015, the hay production from Perennial Mix were not estimated that resulted into a negative net return. SW = Spring Wheat; WW = Winter Wheat.

Water Use Efficiency of Durum

Durum is included in five of the different cropping sequences. The soil wetness at the time of durum planting varies depending on the water use characteristics of the preceding crop. This provides an opportunity to determine the effect of water availability on durum yield. Beginning in 2015, we measured soil water during the entire growing season at one- to two- week intervals. Thus, data from four years are available for this analysis.

This year, the soil was slightly wetter than the 4-yr average conditions at both planting and at harvest (Table S1). The soil water extraction was less than the 4-yr average. Rainfall during the 2018 growing season was greater than any of the previous three years, consequently, the fraction of water from rain was at a 4-yr high. This year, durum yields averaged 50.5 bu/a, which was a 4-yr high, and water use efficiency, defined as the bushels produced per inch of water used, was also at a 4-yr high.

A more realistic view of the relationship between crop water use and yield is to determine the amount of water required to grow the plant separately from the amount of water required to produce grain. The first value is termed the “initial yield point” and the second is termed the “yield increment”. These values can be calculated by a statistical procedure called “linear regression”. Because the initial yield point value cannot be determined accurately if the data set is too small, data from all 4 years were combined, resulting in a data set of 20 points (i.e., 4 years × 5 treatments). The values determined from this data set were 2.6 inches of water for the initial yield point and 5.2 bushels per inch of water for the yield increment. This initial yield point value is near the lower end of values found in previous studies, whereas this yield increment value is quite typical. The reason these values are so favorable is not completely determined, however improved management practices including no-till is likely a major cause.

Table S1: Relationship of durum yield and crop water use.

	2015	2016	2017	2018	4-yr avg
Soil water at planting *(inches in top 4 ft)*	8.69	10.25	11.31	10.34	10.15
Soil water at harvest *(inches in top 4 ft)*	5.69	6.33	5.91	6.80	6.18
Soil water extracted *(inches)*	3.00	3.93	5.40	3.54	3.97
Rainfall, planting to harvest *(inches)*	6.94	7.67	2.31	8.49	6.35
Total crop water use *(inches)*	9.94	11.60	7.71	12.03	10.32
Fraction of water from rain	70%	66%	30%	71%	59%
Durum yield *(bu/a)*	36.6	45.6	27.5	50.5	40.03
Durum WUE *(bu/in)*	3.64	3.92	3.56	4.20	3.83

Soil Health Data

Background

Potential Carbon Mineralization (PCM) is a measure of soil respiration – microbial breakdown of soil carbon. It is measured by wetting the soil and measuring the amount of carbon released after a 10 day incubation. High PCM is associated with high microbial activity in the soil, which is necessary to make nutrients available to plants. Microbial Biomass Carbon (MBC) is a measurement of the carbon contained within the living component of soil organic matter (i.e. bacteria and fungi). High levels of MBC is generally considered desirable and associated with a “healthy” soil.

Experimental Methods

Soil samples were collected from a depth of 2-4 inches at 5 locations within each plot after crop harvest in the fall of 2016 and 2017. For PCM and MBC, the soil was air dried, sieved and stored at -4°F until analysis. PCM and MBC were measured by incubating wet soil and measuring amount of CO2 generated before and after treatment with chloroform.

Results

Soil collected from durum plots different significantly by rotation in microbial biomass carbon, where durum cropped in a durum-fallow rotation had significantly lower soil microbial biomass carbon than a 5 year diverse rotation sown to a cover crop one out of five years - Dur/BP1/Pea/Corn/Saff (Fig SH1). Continuous cropping of durum (Dur-Dur) or a diverse crop rotations without cover crops (Dur/WW/Pea/Corn/Saff) was not sufficient to improve soil microbial biomass carbon from the levels in a durum-fallow rotation (Fig SH1).

Potential mineralizable carbon (PMC) was highest under the perennial grass treatment which has been undisturbed for five years (Fig SH2). PMC in cover crop, safflower and pea plots were not significantly different from the perennial grass plots, however (Fig SH2). Corn, durum, winter wheat and fallow plots had significantly lower PMC than the perennial grass mix (Fig SH2).

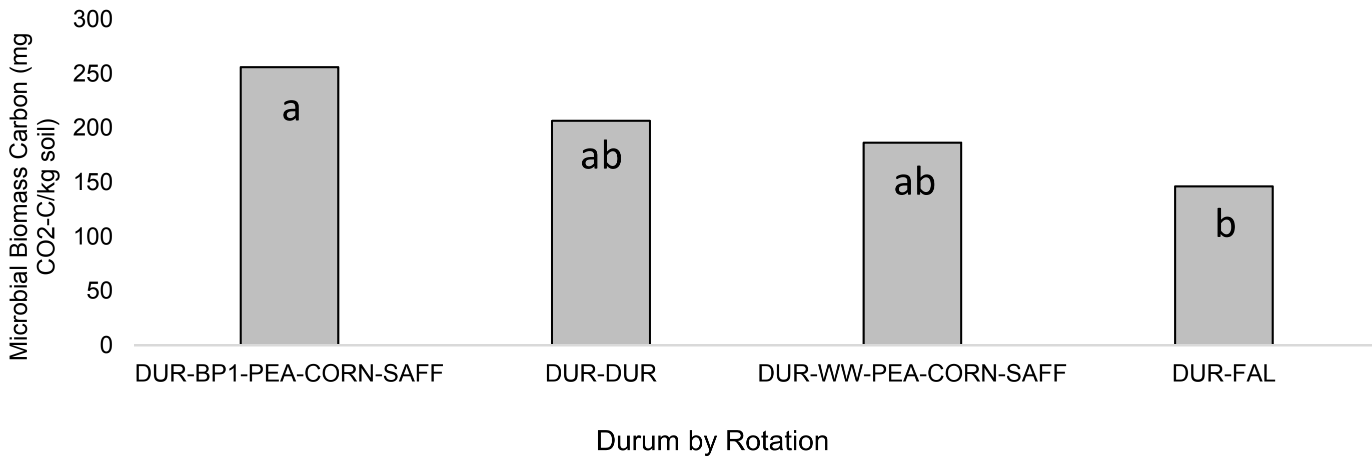

Figure SH1. Microbial Biomass Carbon measured under plots cropped to durum by rotation. Statistically significant differences are indicated by different letters as determined by Student's t test. (α<0.05). Dur = durum, WW = winter wheat, FAL = fallow, SAFF = Safflower, BP1 = cover crop mix. Data is combined results from 2017 and 2016.

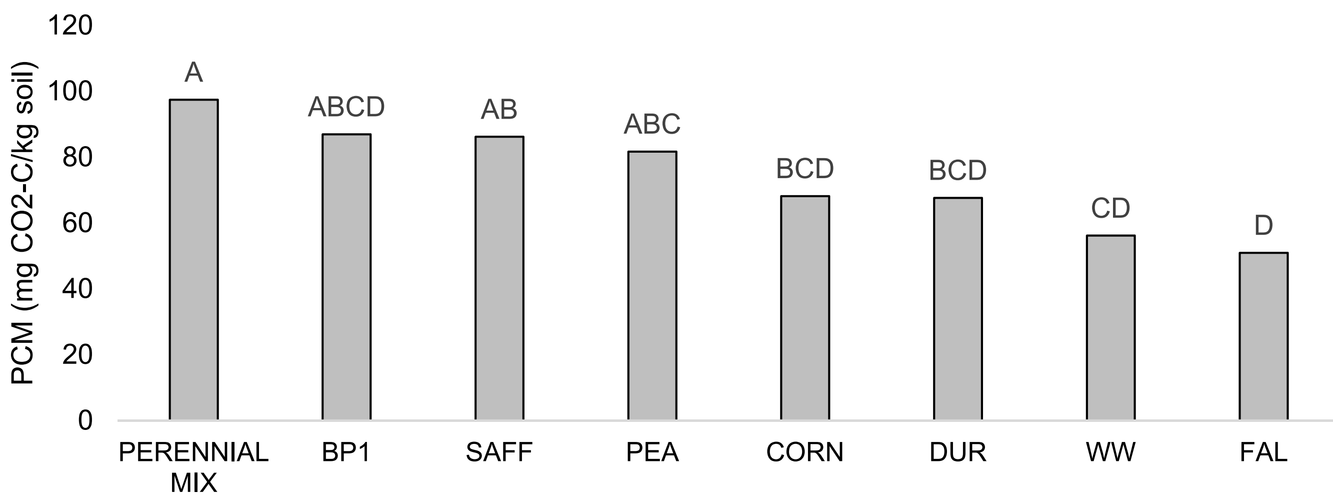

Figure SH2. Potentially Carbon Mineralization measured under different crops. Statistically significant differences are indicated by different letters as determined by Student's t test. (α<0.05). Dur = durum, WW = winter wheat, FAL = fallow, SAFF = Safflower, BP1 = cover crop mix. Data is combined results from 2017 and 2016.

Conclusions

Full season cover crops within a diverse rotation can benefit growers by increasing soil microbial biomass carbon. Microbial biomass is an early indicator of changes in organic matter in the soil. These rotations have only been in place for five years – one full cycle. Thus, in the long term, inclusion of full season cover crops within a rotation may increase soil organic matter more quickly.

Potential carbon mineralization was highest in the perennial grass mixture. This soil has been undisturbed for 5 years and has not received any fertilizer. Thus, these results suggest that the high microbial activity is associated with the presence of the living plant cover. The full season cover crop, safflower and pea had similar levels of PCM as the perennial grass mixture, indicating that these treatments stimulate soil microbial activity. As expected, the fallow treatment had the lowest PCM and corn, durum and winter wheat were not significantly different from fallow. In an annual cropping system, it is important to note that soil respiration also represents a loss of soil carbon to the atmosphere as carbon dioxide – so while PCM is high in the perennial mix treatment – carbon is also going back into the soil via plant roots and plant residue breakdown. Where residue is being consistently removed through baling high PCM may result in net soil loss of carbon. Thus, it is important to balance crops that spur much microbial activity (pea/safflower) with those that have more recalcitrant crop residues (ex. wheat) and to leave sufficient crop residue in the field.