Influences of manure and fertilizer application in corn-soybean-spring wheat/cover crops rotation on Water availability and quality, Soil Fertility, and Crop Yield.
Final Report
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Collaborator: Anuoluwa Sangotayo (PhD student started in Fall 2020).

Summary. Soils managed with manure and inorganic fertilizers have sometime issues of higher N and P losses. Therefore, diversifying the crop rotations with the inclusion of cover crops can help in minimizing the N losses while maintaining adequate N supply for crop yields. Cover crops are beneficial in enhancing soil health and water quality. Further, manure and fertilization management with cover crops can improve soil water storage and availability, and the crop yield. Thus, the proposed project will focus on comparing the soil organic carbon, N losses, soil health, water retention and availability, and crop yield as impacted by different manure and inorganic nitrogen (N) fertilizer rates under corn-soybean-spring wheat/cover crop rotation. *The NREC provided funding for the past few years (FY 2017-2020) to support the proposed sites to monitor the soil health and crop yield in response to different manure and inorganic fertilizer application. The current proposal is an extension of these activities with the inclusion of cover crops and adding new objectives that include water retention and availability and nitrate leaching leveraging the previous work. This proposal will help in incorporation of cover crops at both the sites, and changing the corn-soybean rotation to corn-soybean-spring wheat/cover crop rotation.*

Goal and Objectives: The primary goal of this project is provide information to producers on the optimum rates of inorganic fertilizer and manure for enhancing soil fertility and crop yields without losing extra N and P losses. The specific objectives of the project are to:

1) **Soil Organic Carbon, Water Retention and Availability**. Assess the impacts of manure and inorganic fertilizer applications under corn-soybean-spring wheat-cover crop (*multispecies* cover crops that include radish, clovers, sorghum, turnips, oats) rotation on soil water retention and available water content for 0-10, 10-20, 20-30 and 30-40 cm depths at two sites (Beresford and Brookings).
2) **Soil Health and Water Quality**. Assess the impacts of manure and inorganic fertilizer applications on water quality (nitrate leaching) (0-120 cm depth).
3) **Crop Yield**. Assess the impacts of manure and inorganic fertilizer applications on crop growth parameters, nutrients in plants, and N use efficiency.

Soil water holding and retention was better at all soil depth for treatments received manure compared to the control or fertilizer treatments (Figure 1) Differences between the control and the manure treatments were larger near the surface, and the deeper soil layers (12-16”). The differences in water retention were explained by the distribution of the different pore sizes, as the manure treated soils had larger proportion of micropores, especially in the 12-16” soil depths (Figure 2)

Soil health was assessed through soil microbial N and C content. Higher microbial C mass was observed with manure treatments during the crop phase compared to control or fertilizer management at both locations, and higher biomass N content was observed in Brookings (Table 1). We measured differences in potential carbon mineralization only at the Brookings site (Table 2). Enzyme activities were higher in treatments that received manure at both locations, especially during the crop growth phase (Figures 3 and 4) showing the benefit of manure application on soil biological activities.

Grain yields were higher with the medium and high manure rates and the fertilizer treatment compared to the control at Brookings (Table 3). Fertilizers were spread in the spring improving their efficiency. Manure was spread in the previous fall, and the longer time between the application and the crop nutrients' need may contribute to these results. At Beresford, both manure a fertilizer treatment yielded better than the control, except the high manure treatment (Table 3).

Nutrient uptake and recovery showed similar patterns to the yield. The high manure and high fertilizer treatments increased nutrient uptake in most of the plant partitions, as well as the total N uptake compared to the P and N based manure applications or to the control treatment (Tables 4 and 5). However, the N harvest index (proportion of N in the grain relative to total N uptake) was not statistically different among the treatments; numerically we observed larger N allocation with the two highest N treatments.

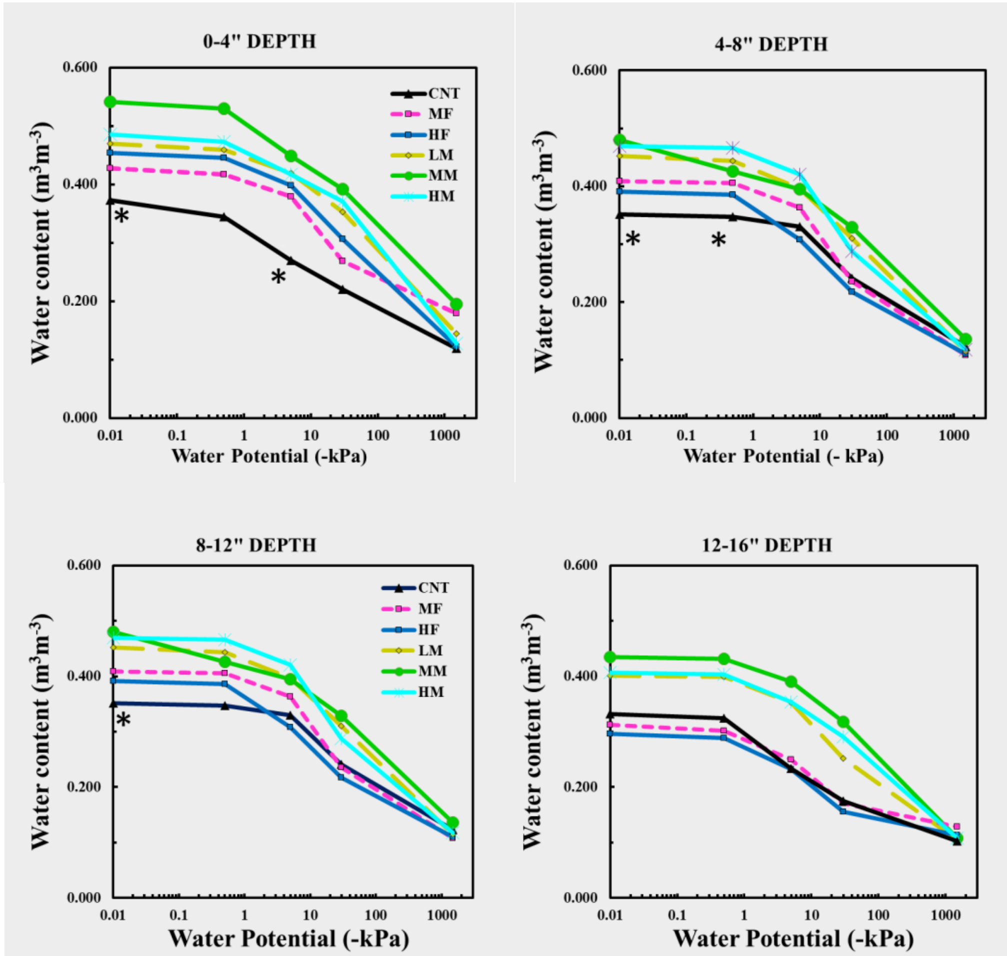

Figure 1. Long-term fertilizer management effect on water holding and retention at various soil depths near Brookings, SD Treatments were medium fertilizer (MF), high fertilizer (HF), low manure (LM), medium manure (MM), high manure (HM) rate applications and control (CNT)

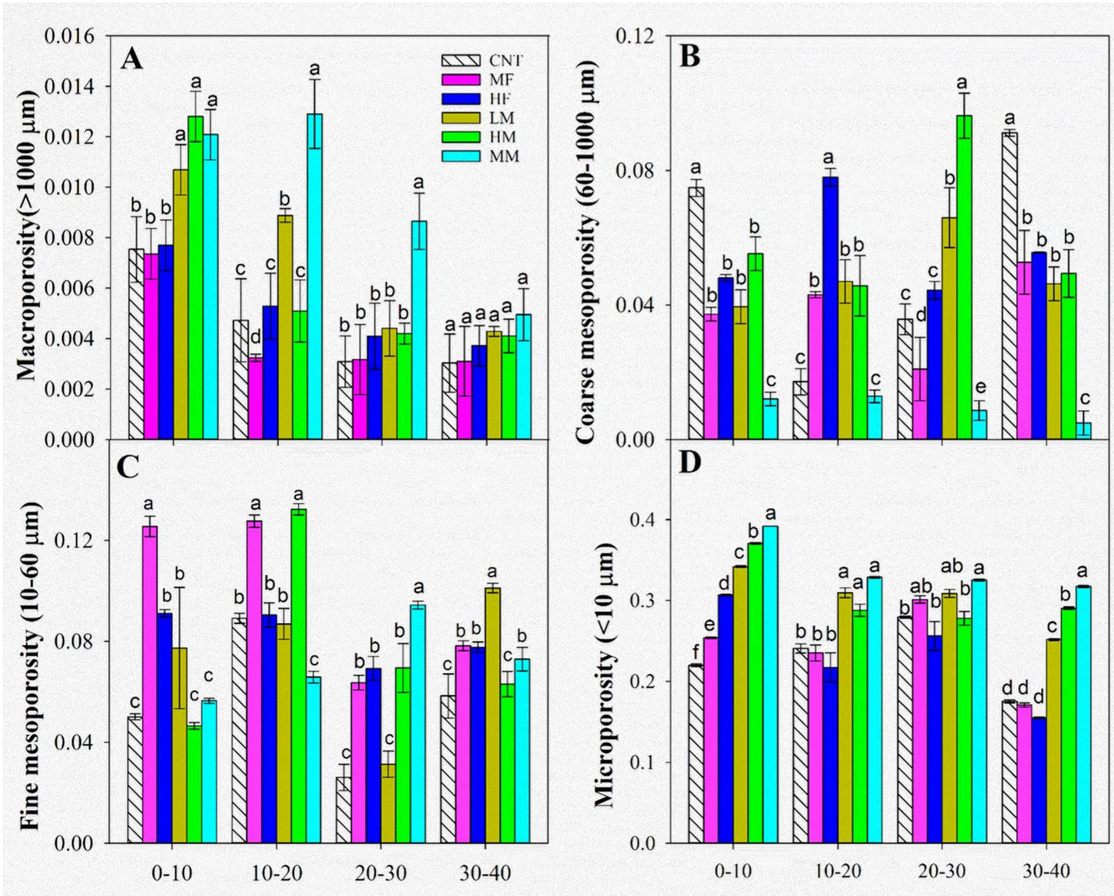

Figure 2. Macro-, meso- and micro-porosity distribution influenced by the treatments of long-term medium fertilizer (MF), high fertilizer (HF), low manure (LM), medium manure (MM), high manure (HM) rate applications and control (CNT) at 0-16” (0-40cm) soil depth.

Table 1. Long-term fertilizer management effect on microbial biomass carbon and nitrogen concentration near Brookings, SD and Beresford, SD

Site	Brookings		Beresford		Brookings		Beresford	
Time of Sampling	DSW	PHSW	DSW	PHSW	DSW	PHSW	DSW	PHSW
Treatments	Microbial Biomass Carbon (MBC) ------------- (mg kg $^{-1}$) -------------				Microbial Biomass Nitrogen (MBN) ------------- (mg kg $^{-1}$) -------------			
LM	690 bc†	1604 a	1141 b	1820 a	253 bc	333 a	399 a	452 a
MM	745 ab	1513 a	1306 b	1752 a	301 b	318 a	231 a	367 a
HM	928 a	2029 a	1987 a	2404 a	522 a	308 a	268 a	445 a
MF	498 cd	1478 a	999 bc	2069 a	248 bc	275 a	385 a	440 a
HF	800 ab	1816 a	1381 ab	1817 a	437 a	265 a	301 a	337 a
CK	340 d	1320 a	723 c	1563 a	209 c	251 a	192 a	312 a
Analysis of variance Pr >F								
Treatment	**<0.0001**	0.3669	**<0.0001**	0.9198	**<0.0001**	0.8282	0.1090	0.9314
M vs. F	**0.0198**	0.8345	**0.0147**	0.9255	0.4282	0.3055	0.3005	0.4981
Sampling Time	**<0.0001**		**0.0185**		0.5138		0.0711	

†Mean values followed by different lower letters between each treatment within each sampling time represent significant differences due to manure and inorganic fertilizer application at $P < 0.05$. DSW, During Spring Wheat; PHSW, Post-Harvest Spring Wheat; LM, low manure rate based on recommended phosphorus rate; MM, medium manure rate based on recommended nitrogen rate; HM, high manure rate based on double of the recommended nitrogen rate; MF, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 2. Long-term fertilizer management effect on potential carbon mineralization near Brookings, SD and Beresford, SD

Site	**Brookings**		**Beresford**	
Time of Sampling	DSW	PHSW	DSW	PHSW
Treatments	Potential Carbon Mineralization ---------(mg kg $^{-1}$) -------------			
LM	2.49 ab†	2.25 ab	1.97 a	2.26 a
MM	2.97 a	2.36 a	1.91 ab	2.07 ab
HM	2.28 b	1.77 bc	1.04 ab	1.45 bc
MF	2.06 b	1.82 bc	1.67 ab	1.79 abc
HF	2.16 b	1.99 abc	1.11 ab	1.47 bc
CK	1.94 b	1.48 c	1.58 ab	1.32 c
Analysis of variance Pr >F				
Treatment	**0.0004**	**0.0006**	**0.0140**	**0.018**
M vs. F	**0.0020**	**0.0409**	0.2217	0.4940

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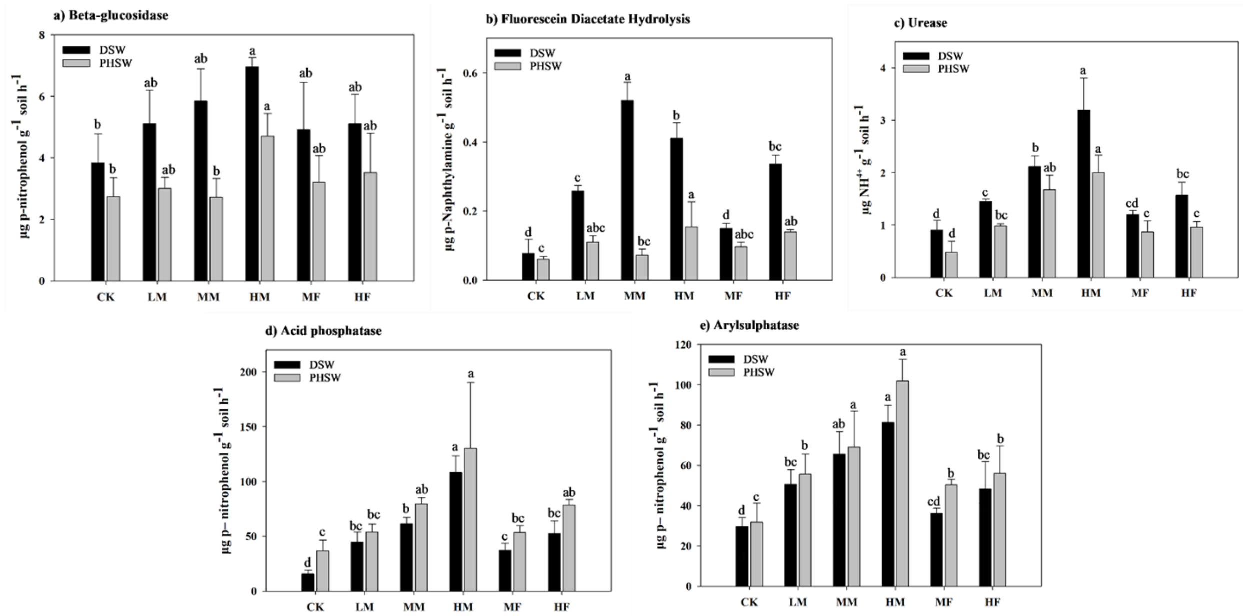

Figure 3. ß-glucosidase (a), fluorescein diacetate hydrolysis (b), urease (c), acid phosphatase (d), and arylsulphatase (e) enzymes activities influenced by the treatments of long-term medium fertilizer (MF), high fertilizer (HF), low manure (LM), medium manure (MM), high manure (HM) rate applications and control (CK) near Brookings, SD.

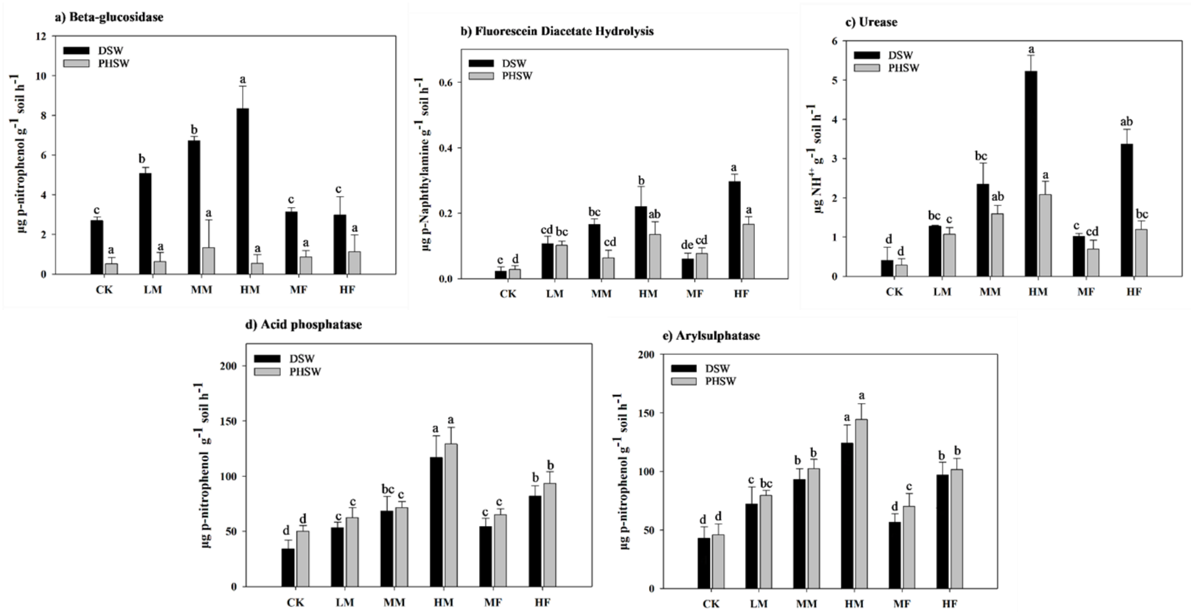

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Table 3. Long-term fertilizer management effect on grain yield near Brookings, SD and Beresford, SD

Treatment	Brookings	Beresford
CK	52.8 d[†]	105.4 c
LM	54.7 d	132.3 b
MM	85.2 c	134.9 ab
HM	148.3 a	117.3 bc
MF	127.4 b	132.0 b
HF	157.2 a	153.1 a
Pr<F		
Treatment	**<.0001**	**0.002**

[†]Mean values followed by different lower letters between each treatment within each sampling time represent significant differences due to manure and inorganic fertilizer application at $p < 0.05$.
LM, low manure rate based on recommended phosphorus rate; MM, medium manure rate based on recommended nitrogen rate; HM, high manure rate based on double of the recommended nitrogen rate; MF, recommended fertilizer; HF, high fertilizer; and CK, control with no manure application.

Table 4. N uptake and partitioning into stover, grain cob at physiological maturity, total N uptake and N harvest index near Brookings, SD.

Treatment	Stover (kg ha^{-1})	Grain (kg ha^{-1})	Cob (kg ha^{-1})	Total (kg ha^{-1})	NHI Kg N grain kg^{-1} N biomass
CK	9.7 b†	31.3 c	2.18c	43.2 c	72.6
LM	8.7 b	24.5 c	1.64 c	34.8 c	70.3
MM	12.0 b	30.6 c	2.27 c	44.8 c	67.3
HM	29.9 a	82.9 ab	4.88 ab	117.6 ab	69.7
MF	14.7 b	63.8 bc	3.22 bc	81.7 bc	77.0
HF	27.4 a	113.4 a	6.16 a	147.0 a	77.1
Pr<F					
Treatment	**0.002**	**0.007**	**0.0009**	**0.005**	**0.058**

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Table 5. N uptake and partitioning into stover, grain cob at physiological maturity, total N uptake and N harvest index near Beresford, SD.

Treatment	Stover (kg ha^{-1})	Grain (kg ha^{-1})	Cob (kg ha^{-1})	Total (kg ha^{-1})	NHI Kg N grain kg^{-1} N biomass
CK	21.1	46.2 b†	3.24 c	70.5 c	65.7
LM	22.9	32.1 b	2.97 c	58.0 c	56.3
MM	31.0	46.1 b	3.64 bc	80.8 c	57.0
HM	43.7	135.5 a	10.11 a	182.6 ab	67.8
MF	27.0	90.0 ab	5.36 bc	122.3 bc	73.2
HF	34.8	140.1 a	7.65 ab	189.3 a	73.6
Pr<F					
Treatment	**0.11**	**0.02**	**0.02**	**0.004**	**0.25**

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Influences of manure and fertilizer application in corn-soybean-spring wheat/cover crops rotation on Water availability and quality, Soil Fertility, and Crop Yield-YEAR 2.

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Objective 1. Soil Organic Carbon, Water Retention and Availability. Assess the impacts of manure and inorganic fertilizer applications under corn-soybean-spring wheat-cover crop (multispecies cover crops that include radish, clovers, sorghum, turnips, oats) rotation on soil water retention and available water content for 0-10, 10-20, 20-30 and 30-40 cm depths at two sites (Beresford and Brookings).

Objective 2. Soil Health and Water Quality. Assess the impacts of manure and inorganic fertilizer applications on water quality (nitrate leaching) (0-120 cm depth).

Objective 3. Crop Yield. Assess the impacts of manure and inorganic fertilizer applications on crop growth parameters, nutrients in plants, and N use efficiency.

The long-term sites were established in 2003 near Beresford, and in 2008 near Brookings. Each site included six treatments, that included: three manure application rates; low manure (LM) contained a quantity of manure based on the recommended phosphorous requirement, medium manure (MM) contained a quantity of manure based on recommended nitrogen requirement, and high manure (HM) contained a quantity of manure-based on double the recommended nitrogen requirement, two inorganic fertilizer application rate; medium fertilizer (MF) contained the suggested inorganic fertilizer rate, high fertilizer (HF) contained a high fertilizer rate and a control treatment (CK) which did not receive manure and fertilizer. Treatments were arranged in a randomized complete block design with four replicates.

The soybean plots were established on May 19th in Beresford, and on May 20th near Brookings in 2022.

Soil surface GHG fluxes were monitored from July through November 2020 and April through October 2021, and from May through October 2022 where gas samples were taken once a week dependent on the weather conditions. Static closed chamber technique was used for measuring GHG fluxes (Parkin & Venterea, 2010), where Polyvinyl chloride (PVC) static chambers (25 cm diameter × 15 cm height) were installed in plot with medium manure (MM), medium fertilizer (MF), and control (CK) which received no manure and no fertilizer to monitor soil surface GHG fluxes. The chamber was installed to a depth of 5 cm between crop with minimum soil disturbance and were removed only during the field operations. In addition to soil surface GHG flux monitoring, during each sampling time, soil moisture was measured volumetrically using a HH2 moisture sensor (Delta-T-Devices, Cambridge, England) and temperature was measured using a thermometer (Taylor 14769 Digital LCD folding thermometer) at 0-5 cm soil depth, respectively. Gas samples were collected at 0-, 20-and 40- min intervals using a 10-ml syringe. It was collected between 8:00 am and noon to minimize the effect of diurnal variations on GHG fluxes. These samples were taken via a chamber septum and transferred to a 10-ml argon-filled sterilized vials sealed with a gas-tight septum. Gas concentrations of CO_2, CH_4, and N_2O were measured within 2 to 3 days of sampling using a Gas Chromatograph (GC-2014; Shimadzu, Columbia, MD, USA) using a lepton capture detector each at 260 °C for N_2O, and a flame ionization detector for CO_2 and CH_4.

There was no statistical difference in GHG emissions amongst measured treatments in 2020 and 2021 (Figure 1). The peak CO_2 and N_2O emissions was observed in July both in 2020 and in 2021 as compared to other months. Both treatments that received manure or fertilizer application tended to have higher GHG emissions.

There were no statistical differences in cumulative CO_2 emission between the treatments in 2020 and 2021 (Table 1). The MM treatment had similar N2O emission to the control treatments, but about half of N_2O emission compared to the fertilizer treatment in 2020 (Table 1). In 2021, both treatments receiving nutrient applications (MM and MF) produced higher cumulative N_2O emission compared to the non-fertilized control treatment (Table 1). In 2020, cumulative CH_4 emissions showed similar results to the N_2O emission, MF treatment produced higher CH_4 emissions compared to the other two treatments (Table 1)

In 2022, soybean grain yield did not differ due to the different long-term fertilizer treatments (Tables 2 and 4). The biomass accumulation and partitioning at full seed growth (R6) stage did not statistically differ either among the different treatments (Tables 2 and 3). Similarly to the biomass accumulation whole plant nutrient (N, P, K) uptake and pod nutrient accumulation were not different among the treatments.

In 2022 treatments did not receive manure or fertilizer application as soybean was grown in the crop rotation. These results also provide some indication about the nutrient supply utilizing long-term manure in crop rotations. Drought impacted crop development and yield (especially at the Beresford site), which may also influenced nutrient accessibility and availability.

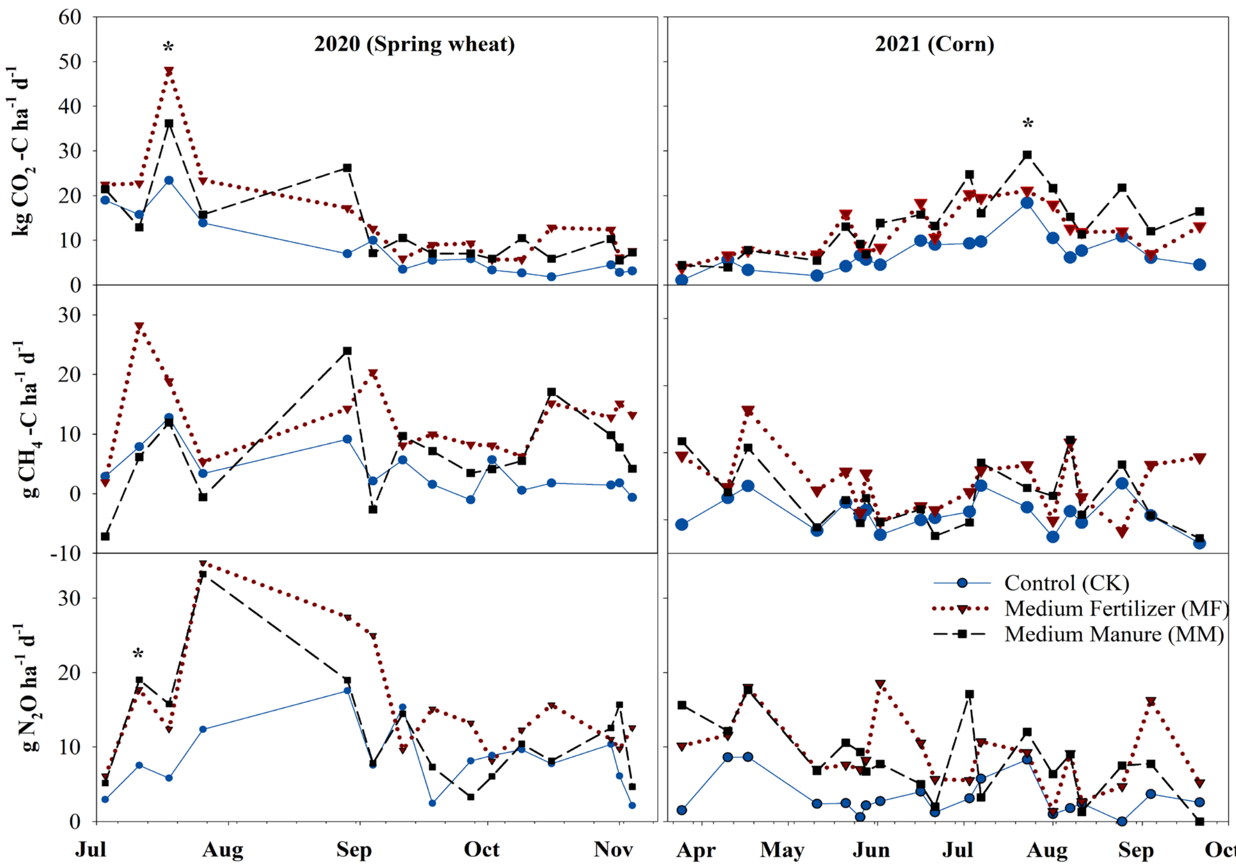

Figure 1: Preliminary data on GHG fluxes as influenced by long-term manure and fertilizer management under corn-soybean-spring wheat rotation

* shows significant difference within the date of GHG emissions

Table 1: Preliminary data on cumulative annual GHG emissions as influenced by long-term manure and fertilizer management under corn-soybean-spring wheat rotation.

Treatments	CO_2 kg ha^{-1} d^{-1}		N_2O g ha^{-1} d^{-1}		CH_4 g ha^{-1} d^{-1}	
	2020 (Spring wheat)	2021 (Corn)	2020 (Spring wheat)	2021 (Corn)	2020 (Spring wheat)	2021 (Corn)
MM	706.81^{a†}	1235.23^{a}	402.02^{b}	492.45^{a}	644.49^{b}	868.33^{a}
MF	885.19^{a}	796.87^{a}	800.59^{a}	459.13^{a}	923.99^{a}	713.20^{a}
CK	538.92^{a}	763.67^{b}	268.06^{b}	435.47^{b}	584.22^{b}	549.94^{a}

† Means within the same column followed by different superscript letters are significantly different at $P < .05$.

Table 2. Long-term fertilization effect on soybean grain yield, final stand counts, biomass accumulation at full seed (R6) and its partitioning near Brookings in 2022.

Treatment	Grain Yield (bu ac^{-1})	Final stand counts (plants ac^{-1})	Dry matter accumulation (lbs ac^{-1})			
			Leaves	Stems	Pods	Total
Control (CK)[†]	71.60	97,700	120 bc	2,538	6,684	9,340
Low manure (LW)	70.09	95,000	83 c	2,382	5,873	8,338
Medium Manure (MM)	68.58	95,700	186 ab	3,340	8,201	11,727
High Manure (HM)	75.11	85,700	83 c	2,374	5,688	8,145
Medium Fertilizer (MF)	73.57	93,700	250 a	3,420	7,967	11,637
High Fertilizer (HF)	72.96	89,700	144 bc	2,627	6,318	9,089
***p* < F**						
Treatment	0.30	0.85	0.02	0.13	0.32	0.23

[†]low manure (LM) contained a quantity of manure based on the recommended phosphorous requirement, medium manure (MM) contained a quantity of manure based on recommended nitrogen requirement, and high manure (HM) contained a quantity of manure-based on double the recommended nitrogen requirement, two inorganic fertilizer application rate; medium fertilizer (MF) contained the suggested inorganic fertilizer rate, high fertilizer (HF) contained a high fertilizer rate and a control treatment (CK) which did not receive manure and fertilizer

Table 3. Long-term fertilization effect on soybean N, P, and S whole plant nutrient uptake and N, P, and S content in the pod at full seed (R6) near Brookings in 2022.

Treatment	**Whole plant nutrient uptake**			**Nutrient accumulation in pod**		
	N	**P**	**S**	**N**	**P**	**S**
		(lbs ac^{-1})			**(lbs ac^{-1})**	
Control (CK)†	334	33	20	311	31	17
Low manure (LW)	307	31	18	287	29	16
Medium Manure (MM)	417	43	24	386	39	21
High Manure (HM)	305	35	19	284	31	16
Medium Fertilizer (MF)	440	45	25	405	41	22
High Fertilizer (HF)	345	40	20	322	31	17
***p* < F**						
Treatment	0.34	0.38	0.44	0.40	0.47	0.50

†low manure (LM) contained a quantity of manure based on the recommended phosphorous requirement, medium manure (MM) contained a quantity of manure based on recommended nitrogen requirement, and high manure (HM) contained a quantity of manure-based on double the recommended nitrogen requirement, two inorganic fertilizer application rate; medium fertilizer (MF) contained the suggested inorganic fertilizer rate, high fertilizer (HF) contained a high fertilizer rate and a control treatment (CK) which did not receive manure and fertilizer

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Treatment	**Grain Yield (bu ac^{-1})**	**Final stand counts (plants ac^{-1})**	**Dry matter accumulation (lbs ac^{-1})**			
			Leaves	**Stems**	**Pods**	**Total**
Control (CK)[†]	31.68	77,700	1,622	629	3,058	5,309
Low manure (LW)	34.00	89,700	2,205	683	4,179	7,067
Medium Manure (MM)	44.39	84,700	1,699	594	3,403	5,696
High Manure (HM)	32.57	71,700	1,833	882	3,009	5,725
Medium Fertilizer (MF)	31.73	77,400	1,938	945	3,766	6,649
High Fertilizer (HF)	30.72	75,700	1,650	690	3,442	5,782
***p* < F**						
Treatment	0.39	0.64	0.20	0.38	0.23	0.32

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	Whole plant nutrient uptake			Nutrient accumulation in pod		
Treatment	**N**	**P**	**S**	**N**	**P**	**S**
		(lbs ac^{-1})			**(lbs ac^{-1})**	
Control (CK)†	178	12	9	140	10	6
Low manure (LW)	246	20	14	193	16	10
Medium Manure (MM)	199	15	11	158	13	8
High Manure (HM)	203	14	11	142	11	7
Medium Fertilizer (MF)	207	15	10	157	12	7
High Fertilizer (HF)	193	14	10	152	12	8
***p* < F**						
Treatment	0.27	0.15	0.17	0.23	0.14	0.19

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