KERNZA IN WYOMING: EVALUATING PERENNIAL GRAINS TO REVITALIZE WYOMING DRYLAND AGRICULTURE

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ABSTRACT

Kernza, a perennial grain crop harvested from intermediate wheatgrass, promises to provide a sustainable alternative to wheat-fallow agriculture that can build soil health while producing food for a growing population. Kernza had not previously been planted in Wyoming, where the semiarid landscape presents unique challenges yet stands to particularly benefit from a perennial crop. Kernza is being grown from spring 2021-2024 at several farms in southeast Wyoming using various management strategies. We aim to evaluate Kernza's effects on soil fertility, carbon sequestration, and microbial activity by comparing Kernza fields to both wheat-fallow and perennial grassland. So far, baseline soil sampling has shown differences in soil health indicators between annual and perennial systems. In particular, we found higher surface (0-5cm) microbial enzyme activity and labile organic matter pools, and more stratification between depths (0-5 and 5-15cm) in the perennial system. In future years, we expect that fields transitioning from annual cropping to Kernza will become more similar to perennial grassland in terms of these soil health indicators.

INTRODUCTION

Wyoming Wheat-Fallow

Cereal grains make up the majority of world cropland and fertilizer use, and wheat in particular accounts for one-fifth of the global food supply.[1,2] Winter wheat is the major food crop in the High Plains of Wyoming, yet degraded soils, climate change, and weak markets threaten farming in this region. Additionally, wheat agroecosystems are especially vulnerable to a changing climate.[3] The Western Great Plains is experiencing both land abandonment and land-use change towards Conservation Reserve Program (CRP) land and hay, driven by drought, fluctuating markets, and marginal yields.[4,5] When perennial grassland is converted to annual cropland, even without tillage, root biomass, oxidizable carbon (C), and microbial biomass has been shown to decrease.[6] Though tilled wheat-fallow (W-F) systems in eastern Wyoming have lost 33-63% of their native soil organic C (SOC), converting these systems back to perennials as part of CRP can restore SOC to 90% of that under native grassland after 15 years.[7] Sustaining agriculture in this region will require alternative farming systems that can mimic the native landscape while remaining profitable.[8]

Kernza

Kernza, the first perennial grain crop grown in the US, is harvested from a cultivar of intermediate wheatgrass *(Thinopyrum intermedium)* developed at The Land

Institute. Kernza serves as a replacement for wheat in food products such as cereals, bread, and beer. It grows for three or more years between seedings and can be harvested for both grain and forage. Kernza's deep perennial roots sequester C, curtail soil erosion, and enhance access to water and nutrients. Kernza fields support soil microbial communities more similar to native prairie than to annual wheat, contributing to soil aggregation, microbial C stabilization, and tight nutrient cycling.[9–11] Though Kernza had not been planted in Wyoming prior to this project, it shows promise as a sustainable dryland crop for marginal lands.[12]

We aim to evaluate the effects of Kernza on soil health and C sequestration compared to W-F and CRP. Kernza is being planted at four farms, including the James C. Hageman Sustainable Agriculture Research & Extension Center (SAREC), and yield will be assessed at each. Additionally, we are evaluating soil health and soil microbiology in matched Kernza, W-F, and CRP fields at one farm by analyzing soil physical, chemical, and biological properties. We expect to find that soil properties will become more similar to perennial grassland as W-F fields transition to Kernza. Despite lower yields, higher market prices and soil health benefits could make Kernza a viable option for High Plains wheat farmers.

MATERIALS & METHODS

Site Description & Experimental Design

The High Plains ecoregion that comprises Wyoming's wheat growing region experiences 305-432 mm annual precipitation, 100-125 frost-free days, and a mesic temperature regime (-13/4°C average January min/max, 11/31°C average July min/max). Soils are mainly silty and loamy Mollisols (Agiustolls, Haplustolls) and Entisols (Torriorthents, Torripsamments, Ustorthents).[13]

Ten to twenty acres of Kernza was or will be planted in spring of 2021 or 2022 at each of four farms in southeastern Wyoming, and will be harvested in the summers of 2022, 2023, and 2024 using a plot combine for yield analyses. Winter wheat is grown in a 2-year W-F rotation that includes 14 months of fallow between crops. Perennial grassland is certified CRP land. At SAREC, Kernza was planted in 6 small (5ft x 30ft) irrigated research plots. Half are irrigated up to average precipitation monthly, and half are fully irrigated, in order to evaluate Kernza growth with average and with non-water-limiting conditions. Soil sampling takes place at SAREC and at matched Kernza, W-F, and CRP fields at one farm with three replicate plots in each field.

Data Collection & Analysis

Composite soil samples and bulk density cores are being taken from each plot at two depths (0-5cm and 5-20 cm) in Spring of 2021, 2022, and 2023. In year 3, deeper samples (20-40cm, 40-70cm, and 70-100cm) will be taken at one replicate plot per field for soil characterization (soil texture, soil C, and soil N).

Soil samples are analyzed for the following indicators: total C and N by combustion analysis (Leco Corp., St. Joseph, MI), inorganic C by pressure calcimeter,[14] pH and EC by electrode,[15] aggregate stability using a Yoder-style wet sieving apparatus,[16] bulk density by the core method,[17] gravimetric moisture by oven-drying, dissolved organic C and N (DOC and DON) by extraction with 0.5M K_2SO_4 and the combustion catalytic oxidation/NDIR method (Shimadzu TOC-VCPH with TNM-1, Shimadzu Corporation), microbial biomass C and N (MBC and MBN) by the fumigation-extraction method,[18] nitrate and ammonium (NO_3^- and NH_4^+) by extraction with 0.5M K_2SO_4 and quantification on a microplate spectrophotometer (BioTek, Inc., Winooski, VT),[19,20] mineralizable N (PMN) by 14-day anaerobic incubation,[21] soil protein by autoclaved citrate extractable protein analysis,[16] and active C by reaction with a potassium permanganate solution.[16]

Additionally, we are analyzing potential enzymatic activities by fluorometric or colorimetric reaction with the appropriate substrate and quantification on a microplate reader[22] (Table 1) and microbial community composition using phospholipid fatty acid (PLFA) analysis.[23] Data will be analyzed using ANOVA in Program R to compare soil properties and yield between Kernza, W-F, and CRP land. ANOVAs will be considered statistically significant at $p<0.05$. Principal component analysis (PCA) will also be used to evaluate differences between soil properties among fields.

Table 1: Enzyme names and functions. Adapted from Boggs Lynch (2020) and Stott (2019).

Abbrev	**Enzyme Name**	**Enzyme Function**
CBH	Cellobiohydrolase	Cellulose degradation
BG	Beta-glucosidase	Cellulose degradation
BX	Beta-xylosidase	Hemicellulose degradation
AG	Alpha-glucosidase	Starch hydrolysis
NAG	N-acetyl-beta-Glucosaminidase/ chitinase	Chitin degradation
LAP	Leucine aminopeptidase	Polypeptide degradation
PHOS	Acid phosphatase	Phosphate ester mineralization
SUL	Arylsulfatase	Ester sulfate hydrolysis

RESULTS

Results of baseline sampling indicate that 17 variables significantly differed ($p<0.05$) between CRP and farmland (wheat or fallow) at either 0-5 or 5-15 cm. Enzyme activities and organic matter pools were generally higher in CRP at 0-5 cm but lower at 5-15 cm (Table 2). PCA was able to separate samples by field and horizon, with greater separation between the two depths in CRP than in wheat or fallow (Fig. 3).

Using the matched wheat, fallow, and CRP samples, PERMANOVA found significant differences between horizons ($p=0.017$) and between the three fields ($p=0.01$), but not between the fields when evaluating horizons separately, likely due to small sample sizes. The variables that contributed most to PC1 were PMN, MBC, MBN, and BG, and the variables that contributed most to PC2 were NO3, SOC, DOC, DON, PHOS (Fig. 1).

Table 2. Mean (and standard deviation) of measured soil properties at the two depths in the farmland and CRP at one farm. All enzyme activities are in nmol/hr/g soil. Values that differ significantly ($p<0.05$) are bolded.

		0-5 cm				**5-15 cm**		
	Soil Property	**Farmland**	**CRP**	**p val**		**Farmland**	**CRP**	**p val**
	pH	**8.50 (0.10)**	**8.33 (0.08)**	**0.041**		8.55 (0.11)	8.48 (0.08)	0.337
	EC (uS)	123 (11.5)	120 (10.2)	0.751		**113 (14.5)**	**133 (1.56)**	**0.022**

Physical & Chemical Properties	WSA (%)	**35.3 (15.4)**	**53.2 (6.83)**	**0.047**		59.6 (8.54)	50.5 (15.2)	0.414
	Bulk Density (g/cm^2)	2.34 (0.08)	2.23 (0.13)	0.279		2.39 (0.07)	2.45 (0.02)	0.077
Organic Matter Pools	NO$_3$ (mg/kg)	2.89 (1.94)	2.08 (0.57)	0.379		2.21 1.56	1.27 (0.25	0.352
	PMN (mg/kg)	**4.24 (1.64)**	**9.31 (1.62)**	**0.011**		**2.29 (1.08)**	**3.74 (0.57)**	**0.035**
	SOC (%)	1.24 (0.14)	1.35 (0.10)	0.217		1.15 (0.10)	1.07 (0.07)	0.264
	Total N (%)	0.08 (0.01)	0.09 (0.01)	0.217		**0.08 (0.01)**	**0.07 (0.00)**	**0.012**
	POXC (mg/kg)	311 (118)	288 (76.5)	0.743		299 (117)	295 (50.2)	0.994
	Protein (g/kg)	**3.08 (0.30)**	**3.51 (0.02)**	**0.017**		**2.99 (0.22)**	**2.58 (0.16)**	**0.022**
	DOC (mg/kg)	95.7 (12.0)	62.0 (23.4)	0.116		**82.8 (17.5)**	**55.1 (1.51)**	**0.011**
	DON (mg/kg)	13.6 (3.23)	10.6 (3.97)	0.337		**12.5 (2.76)**	**9.41 (0.67)**	**0.042**
	MBC (mg/kg)	**436 (120)**	**657 (35.9)**	**0.005**		329 (79.9)	361 (47.8)	0.478
	MBN (mg/kg)	**76.4 (14.8)**	**112 (3.63)**	**0.001**		55.6 (7.25)	56.7 (11.5)	0.884
Enzyme Activities	CBH	40.2 (21.9)	51.1 (16.2)	0.436		**13.7 (3.64)**	**6.19 (2.13)**	**0.007**
	PHOS	56.2 (45.0)	23.6 (15.7)	0.157		54.3 (36.9)	19.1 (24.1)	0.135
	NAG	13.4 (5.65)	27.6 (14.5)	0.228		**8.95 (3.87)**	**0.32 (0.50)**	**0.002**
	BX	61.8 (18.4)	78.9 (7.84)	0.092		**31.2 (7.88)**	**16.2 (4.99)**	**0.013**
	AG	48.3 (18.4)	54.0 (12.7)	0.612		**24.2 (4.98)**	**10.8 (3.68)**	**0.005**
	SUL	**10.2 (3.97)**	**14.9 (1.78)**	**0.044**		**7.10 (1.51)**	**4.94 (0.86)**	**0.030**
	LAP	263 (100)	432 (109)	0.093		226 (55.6)	255 (33.7)	0.378
	BG	**137 (43.6)**	**220 (17.3)**	**0.005**		**93.7 (11.9)**	**61.4 (5.22)**	**0.001**

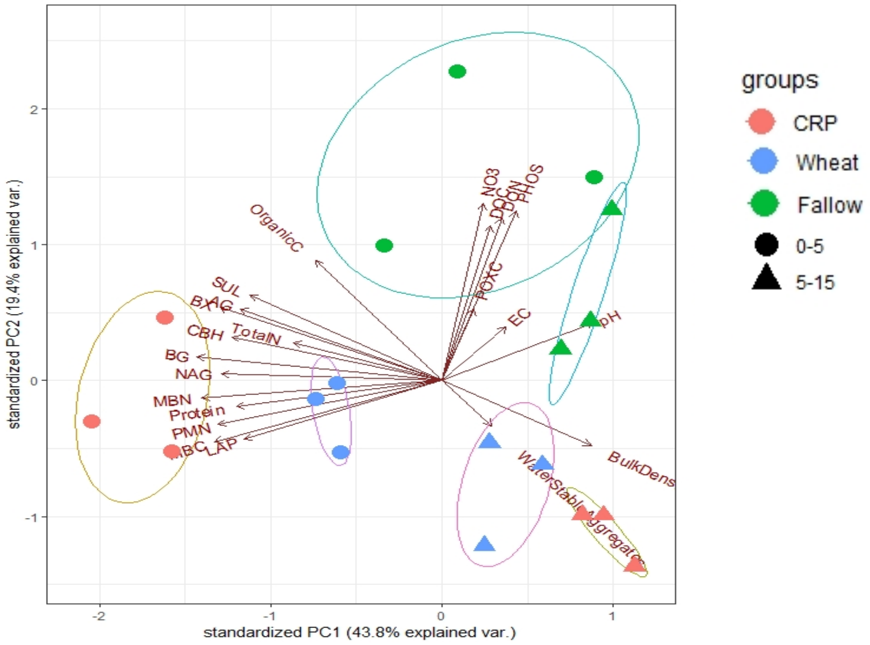

Figure 1. PCA with all measured soil properties (from Table 2) shows the separation between CRP, wheat, and fallow fields at one farm at both depths. The first two principal components explain 62.7% of the variance in the data.

DISCUSSION

Differences Between Annual Cropland and CRP

The clearest difference between CRP and cropland was stratification of enzyme activity and labile organic matter pools in the top 15 cm. The fallow field, which was the most disturbed, was also the most similar between depths (Fig. 1). Microbial biomass and enzyme activities were generally higher in CRP than farmland at 0-5cm but lower at 5-15cm (Table 2). This suggests that in CRP, a higher proportion of microbial activity was occurring near the soil surface. BG and SUL differed between CRP and farmland at both depths, suggesting that these enzymes may be particularly sensitive indicators of soil health change in these systems.

Studies have suggested that stratification of microbial activity and SOC in agricultural fields indicates improved soil health, and that surface SOC can promote functions such as erosion control and nutrient conservation.[24,25] Norton et al. (2012) found SOC accumulation in Wyoming High Plains farmland converted to CRP, as well as higher surface SOC and stratification in perennial prairie than in wheat agriculture.[7]

Future Expectations for Soil Health and Microbial Activity

Though three years will likely not be long enough to observe significant changes in SOC, we expect to find increased labile C pools and microbial activity near the soil surface as fields transition to Kernza. Labile C pools have been shown to be an early indicator of soil health benefit in systems transitioning to Kernza. For example, in Michigan, studies that compared Kernza to annual wheat found 13% higher C mineralization two years after planting,[26]15-18% higher active C during the first three years, and changes in bacterial community in the fourth year.[27]

We expect that microbial indicators (microbial biomass, microbial community composition, and enzyme activities) will be intermediate in Kernza compared to W-F and CRP land. Perennial grain crops support more highly structured and complex food webs relative to annual cropping systems, and the fungal community under Kernza is more similar to native prairie than annual crops.[10,27] PLFA studies comparing Kernza to annual wheat or rye have found increased fungi and AMF (but not bacteria) at 0-10cm after one year, five times greater AMF abundance down to 100cm after two years,[28] and higher total microbial biomass and fungi in 0-15cm after three years.[9] However, further research is needed to evaluate *how* enzyme and SOM stratification may impact soil functions, particularly nutrient cycling, C sequestration, and erosion control.

Overall, this study suggests that stratification of soil enzyme activities and labile organic matter pools could indicate soil change as annual cropland transitions to perennials. Going forwards, this study will help us to better interpret what these various soil health indicators can tell us about land use change and soil health as fields transition from an annual to a perennial grain crop.

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