Testing the Benefits of Balanced Nutrient Use and Crop Diversification on Soil Productivity and Health

By Miles Dyck, Dick Puurveen, and Tom Jensen

A long-term crop rotation study in the Northern Great Plains of Canada helps our understanding of the interactions between crop rotation and nutrient management.

The majority of nutrient management field research is conducted over a short time frame of up to a few years at most. However, when it is possible to continue a set of experimental treatments for many decades, this so called "long-term research" can be very helpful in providing observable results that short-term research cannot offer.

One such long-term research site is 60 miles (100 km) southwest of Edmonton, Alberta, near the Village of Breton located in the Boreal Forest region. These "Breton Classical Plots" were established in 1930 by Dr. Frank Wyatt and Dr. John Newton of the Department of Soils, University of Alberta. Soil in this region is commonly referred to as "Gray Wooded", but soil classification systems refer to the soil as Gray Luvisolic (Canada), Boralf (U.S. Soil Taxonomy), and Albic Luvisol (FAO Soil Classification).

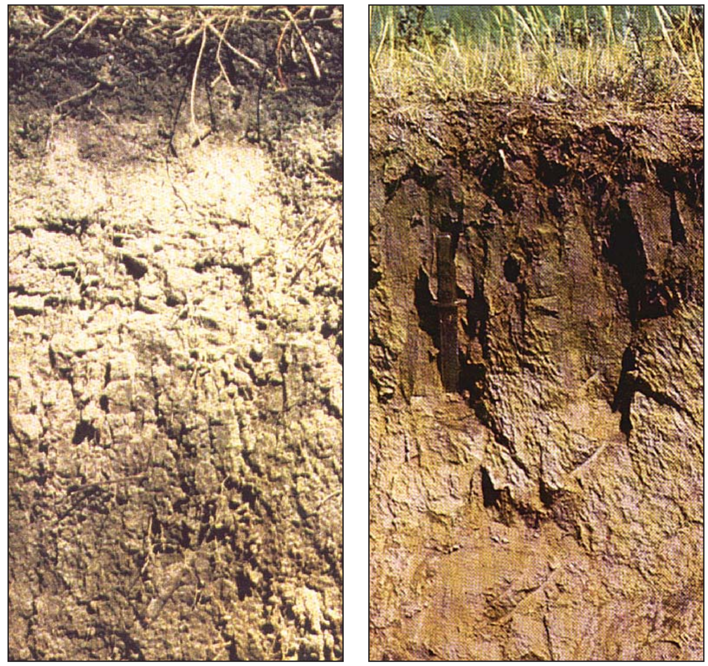
This soil type formed under mixed wood forest and its associated understory vegetation, and is much different than adjacent grassland soils of the Northern Great Plains. As early farm settlers converted the prime, naturally fertile grassland soils to cropped agriculture in the early 1900s, the later arriving settlers began clearing and farming these Gray soils.

The soil's original gray color that is left after clearing and cultivation is the result of the release of organic acids into the soil from forest leaf litter, which leach the top soil horizon of humus and fine clay particles to create a coarser-textured, gray-colored surface horizon 2 to 6 in (5 to 15 cm) thick. Additionally, the accumulated forest litter of plant leaves, deadfall, etc. is not well mixed into the surface soil horizons due to a lack of activity by organisms like earthworms and soil arthropods, and the characteristic tree and shrub roots are coarse and sparsely distributed within the soil (Dyck et al., 2012).

These low organic matter soils are not inherently fertile for arable crop production compared to grassland soils that have humus-enriched surface horizons from the fibrous roots of the abundant grass species. As a result, early settlers had challenges growing adequate crop and forage yields for their mixed farming operations on these soils.

The Breton Classical Plots were initiated to compare two different crop rotations, and select nutrient additions, in order to inform farmers how to improve crop production on these soils. In the beginning, a short rotation with only wheat was compared to a longer rotation including both grain crops and a mixed forage for hay. Minor adjustments have been made over the decades, but since 1941 the site's two rotations have been a Wheat-Fallow (WF) rotation, and a Wheat-Oat-Barley-Hay-Hay (WOBHH) rotation. The hay crop is a brome grass/alfalfa mixture. The forage species are under-seeded into a barley crop during the third year of the five-year rotation and hayed for two years before being terminated in the last year. Wheat is grown the following year. The plots are designed so that all of the crop phases of each rotation are present in the plots each year.

Abbreviations and notes: N = nitrogen; P = phosphorus; K = potassium; S = sulfur; Ca = calcium; Mg = magnesium.



Gray Luvisol soil on the left compared to a Dark Brown Chernozem grassland soil on right. Note the light colored leached top mineral horizon below the forest litter layer in the Gray Luvisol soil, in contrast to the humus-enriched grassland topsoil.

The crop rotation plots are split into the various nutrient addition treatments, one including N, P, K, and S, and as importantly a separate omission treatment for each of the four macronutrients. The nutrient treatments outlined in **Table 1** have been in place since 1980.

Table 1. Nutrient management split plots of the Breton Plots. (Dyck, 2015).

Nutrient treatment	Description
Control	No nutrients applied
Manure	Cattle feedlot manure, sourced locally, rate based on the N content of the manure.
N, P, K, and S	Balanced macronutrients
NSK (-P)	P omission treatment
NPK (-S)	S omission treatment
PKS (-N)	N omission treatment
NPS (-K)	K omission treatment

Table 2. Nutrient source and application rates (lb/A) according to rotation, phase, and fertility treatment.

		Rotation-Phase					
Nutrient	Source	WF-Wheat	WF-Fallow	WOBHH-Wheat	WOBHH-Oats	WOBHH-Barley silage[1]	WOBHH-Forage hay
N	Manure[2]	80[3]	0	78[4]	78[3]	0	0
N	Urea	80	0	45	67	45	0
P_2O_5	Triple super phosphate	46	0	46	46	46	46
K_2O	Potassium chloride	53	0	53	53	53	53
S	Elemental S	18	0	18	18	18	18

[1]Barley silage is under seeded to forage.
[2] Actual application rate of manure is determined by laboratory analysis and based on total N content. Rates of P, K, and S applied with the manure vary slightly due to annual differences in feedlot manure as affected by local availability of grain and hay sources, feed rations and bedding material.
[3] Manure for Wheat-Oats-Barley-Hay-Hay-Oats (WOBHH-Oats) and Wheat Fallow-Wheat (WF-Wheat) is applied in the spring prior to planting.
[4] Manure for the WOBHH-Wheat is applied in the previous fall prior to the plough down of second growth hay of that year.

Soil Organic Matter Trends

The ability to observe long-term changes in soil properties within the Breton plots, as affected by crop rotation and nutrient management, is most useful to nutrient management decision making. Back in 1930, these Gray soils had a soil organic matter (SOM) content of 2.4% after the leaf litter layer was mixed with the leached mineral surface soil layer and underlying B horizon (**Figure 1**). Today, check plots receiving no fertilizer or manure under the WF rotation have seen a 24% loss in SOM down to 1.8%. Long term fertilization with NPKS has lessened this loss to a current 2.2% SOM. Application of manure has increased SOM content up to 3.6%.

In contrast to the WF rotation, the continuously cropped WOBHH rotation has shown improved SOM status under all treatments. Even the check (without nutrient input) has 3.2% SOM, and the NPKS fertilizer treatment up to 3.8%. The manure treatment has greatly increased its SOM content to 4.7%. The positive performance of the manure treatment is based upon the large addition of organic material providing much more than just the N, P, K, and S. However, the gains found in check, with two out of five years in forage production, associated fibrous grass root growth, and symbiotic N fixation inputs from alfalfa, are perhaps more surprising. Another possible benefit from deep-rooted perennial grasses and alfalfa comes from their ability to transport other nutrients (i.e., S, Ca, Mg) to soil surface zones, placing them nearer to growing cereal crop roots.

Wheat Yield Trends

Analysis of wheat yield trends over the last nine years (2007 to 2015) makes clear the current implications of adopting practices over the long-term. Both the WF and WOBHH rotations are yielding lowest in the check treatments where zero nutrient addition is combined with continual removal of nutrients through crop harvest (**Figure 2**).

The highest yielding treatment, also common to both rotations, was the NPKS treatment. However, a divergence is observed between the two rotations, which is related to the impact of omitting K. Wheat yield in the NPS plots has fell relative to the NPKS plots in the WOBHH rotation, but this gap is not seen in the WF rotation. This difference is linked to the greater removal of K under the WOBHH rotation due to the harvest of hay. Over the long-term, this has lowered K availability to a larger degree compared to the WF rotation where only grain is removed from the plots.

The omission of N from the WF rotation results in very low yields that are similar to those obtained in the check. Thus, the addition of N is critical to the productivity of these Gray soils farmed under a WF system. In contrast, the WOBHH benefits from inclusion of an alfalfa forage legume crop within the two-year hay phase. As a result, wheat yields under N omission are far greater than those obtained in check plots.

Given adequate K input, the brome grass/alfalfa mixture in this five-year rotation improves Gray soil productivity and soil health. The inclusion of mixed forages in a crop rotation also lends itself to the mixed farming operations commonly

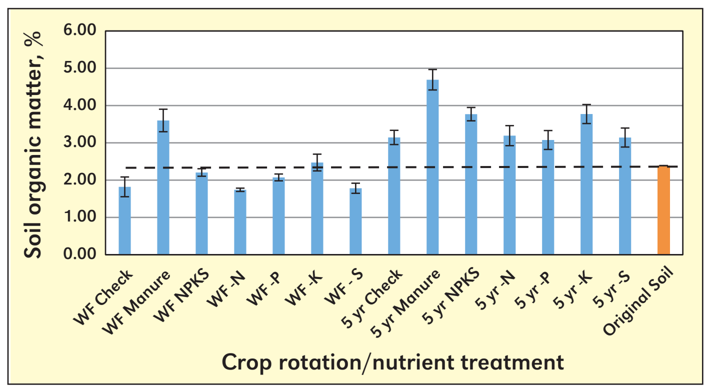


Figure 1. Soil organic matter percentage as affected by crop rotation and nutrient treatment, 2013 soil sample analysis results. Error bars represent the standard error.

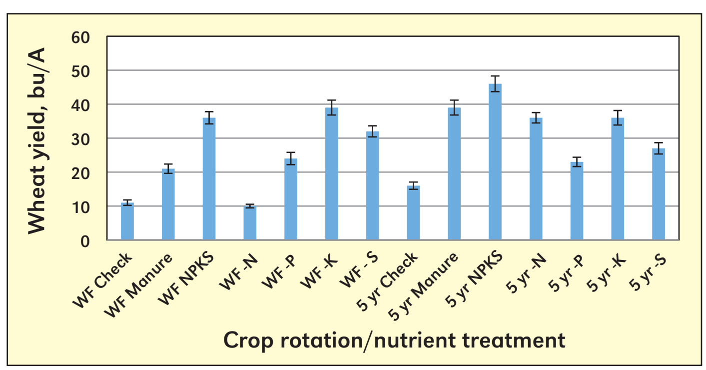


Figure 2. The effect of crop rotation and nutrient treatment on average wheat crop yields in each rotation, over a nine-year period (2007 through 2015). Error bars represent the standard error.

Breton Plots, University of Alberta.

practiced in the area. Integrating crop and livestock, growing mixed forage crops, and returning livestock manure to fields on a regular basis will increase soil productivity compared to only growing small grains or oil seed crops.

The Breton Classical Plots are an extremely valuable legacy of crop rotation and nutrient treatment research, allowing observation of the long-term effects that cannot be measured in the short term. The research results emphasize the positive influence a balanced application of N, P, K, and S can have on a soil, whether applied as fertilizers or livestock manure. There is much discussion presently about what constitutes soil productivity and soil health, and what should be measured to assess the quality of a soil. The SOM and yield potential differences between the combinations of crop rotation and nutrient application are clearly observed at the Breton Plots, and help answer what practices maintain or improve soil capability for agricultural production. BC

Dr. Dyck (E-mail: mdyck@ualberta.ca) and Mr. Puurveen (E-mail: puurveen@ualberta.ca), Renewable Resources Department, University of Alberta, Edmonton, Alberta, Canada. Dr. Jensen is a Director of the IPNI North America Program (E-mail: tjensen@ipni.net).

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