PS&C
Prairie Soils &
Crops Journal

Long-term Field Bioassay of Soil Quality

H.H. Janzen, B.M. Olson, F. Zvomuya, F.J. Larney, and B.H. Ellert

Summary
A field bioassay of soil quality was established in 1990 at the Lethbridge Research Centre to study how measured differences in soil quality affect yield. At each of two sites, 36 diverse soils were deposited onto subsurface soil, and spring wheat was grown, with and without added nitrogen, to measure yield responses. The experiment shows that plants really do 'notice' differences in soil quality, as evident from large and persistent yield differences among plots. Yields were related to measurable soil properties; for example, they tended to increase with organic matter content, but only up to a critical value, above which crop yield was not affected by organic matter content. Further analyses will now measure if and how quickly the differences in quality disappear under common management and climate.

Introduction
For a century or more, scientists have measured how farming affects the soil in hopes of finding those practices that best preserve quality.[8,4] For example, many experiments have measured soil organic matter (or soil carbon) in various long-term treatments to identify those cropping systems that maintain highest levels in the soil. Such studies imply that more is better; that the higher the organic matter content, the better is the quality of the soil. But how do we know that? And is there a point beyond which further increases in organic matter no longer increase soil quality?

In 1990, we established a long-term study to define the relationship between specific soil properties and soil quality for growing spring wheat in the semi-arid prairies of southern Alberta. We removed the original topsoil (A_p horizon) and deposited, in its place, many diverse soils arranged in a replicated design. Spring wheat was then grown in a uniform planting across all plots. In effect, this experiment is a field bioassay of soil quality – it lets the wheat plant tell us, by the size of its yield, how good the 'quality' of the soil is. We especially emphasized soil organic matter, because so many experiments have shown it to be important, but we also measured many other soil properties.

Methodology
The experimental design, described in detail by Olson[7], included 36 soils replicated three times in a randomized complete block design on 5m by 6m main plots, each of which had strips with and without nitrogen (N) fertilizer (Figure 1). This experiment was established at two sites at the Lethbridge Research Centre: one 'dryland' and the other irrigated.

The 36 soils were selected to provide a range of properties; for example, as reflected in the soil color, the highest organic matter content was roughly 10-fold the lowest.[7,10] Many of the soils were obtained from sites at the Lethbridge Research Centre, some from long-term experiments dating back to as early as 1911, and included the topsoil and two sub-soils from nearby areas. Other soils were obtained from sites within about a 100-km radius. The soils were collected at the donor sites using a skid-steer loader, trucked to the common experimental site, and deposited onto well-defined plots using temporary wooden forms. (For this reason, the study is sometimes referred to as the 'Trucking Experiment'.) The experimental site had earlier been carefully stripped of its topsoil and tilled to roughen the interface between subsoil and deposited soil layers. Depth of the deposited soil was, on average, about 19 cm, though it varied somewhat among soils. A large composite sample of soil from each plot was collected in 1990 for future analyses.

Beginning in 1991, the dryland site was seeded to spring wheat every year after applying N fertilizer to appropriate sub-plots. Phosphorus fertilizer was applied with the seed to all plots. In 1992 and 1997, germination was affected by drought, so the crop was killed with herbicide and the plots were fallowed. All plots were managed using strict no-till methods to minimize soil movement and mixing. The irrigated site was initially planted to spring wheat every year, but was shifted to a dryland fallow/wheat system in 1996 and, in 2002/2003, was seeded to a mixture of native grasses which, after slow establishment, now occupy the site (along with some weeds). Most of the research activity to date has focused on the dryland site.

Soils in the dryland site were sampled in 1997, 2004, and 2011, creating a series of samples spanning 21 years (including the original 1990 samples). Soils from the first three sampling times have been extensively analyzed; those from the 2011 sampling are awaiting analysis. For each crop year at the dryland site, yields were obtained from all sub-plots; in recent years, only the total above-ground biomass has been collected and weighed without threshing. We assumed that total yield is more consistent than grain yield as a measure of plant response to soil quality.

Major findings from the study

The experiment showed significant and persistent differences in plant growth among soils.[7,10] In 2004, for example, the last year reported by Zvomuya[10], biomass yield in the highest-yielding soil was more than twice that in the lowest-yielding soil, when no N fertilizer was applied. Applying N reduced but did not eliminate the differences.

Plant biomass was related to various indices of soil quality, including soil organic carbon and related measurements, especially in treatments without N fertilizer.[10] The relationships were not always linear, however. With soil carbon, for example, biomass yield increased sharply with increasing organic carbon up to a critical value (roughly 2% carbon or 3.4% organic matter, for soil not receiving N fertilizer), beyond which further increases in organic carbon no longer influenced biomass yield.[3,10] These findings suggest that a higher soil carbon content does not necessarily mean higher soil quality; only if organic carbon is below the critical value does soil quality (at least for wheat biomass) increase with higher organic carbon (Figure 2). The critical value probably varies with climate and other factors. For example, we might expect that the crop would benefit from higher organic matter content in moist than in dry areas.

Potential advantages of our approach

The experimental design and approach, which is a little unusual, was conceived and developed after much discussion and debate. Past studies linking soil quality to productivity have typically involved correlating yield and specific soil properties at multiple places on a variable landscape.[1,9] Although instructive, such analyses may be confounded by topography.[2,6] On the dry Canadian prairies, for example, yields will often be highest in low-lying areas and lowest on the knolls, a trend usually seen also in organic matter content. This might imply that the high yields in the low-lying areas arise because of high organic matter there. But most likely, the patterns of yield and organic matter both reflect differences in soil moisture content. So we cannot say, for example, that the high organic matter content in low areas *causes* the high yield there. (Indeed, it may be the other way around: the higher organic matter is caused by the higher yield, and hence residue return, over long history.) By holding all other factors the same, as we have tried to do in our study, we can more clearly measure the effect of organic matter on yield.

Qualifiers

As with any experiment, we need to be aware of factors that may skew results. One such limitation is the disturbance involved in establishing the experiment. Such effects cannot be entirely ignored; but is the actual disturbance that much more severe, say, than several tillage events with moldboard plows which lift and turn the entire plow layer? Preliminary studies, in fact, suggested the effects of removal and disturbance may not be as pronounced as some might have expected.[7] The intent of the study, we emphasize, is not to measure how soil quality influences yield at the place where it was collected, but where it was deposited.

A more critical limitation, probably, is that the findings apply only to the ecosystem function specifically measured; namely, the capacity of the soil to grow spring wheat under the conditions of the experimental site. The concept of 'soil quality' is meaningful only when applied to specific functions.[3] The properties optimal for producing wheat yield, for example, may not be the same as those optimal for sequestering atmospheric CO_2, or promoting microbial biodiversity, or growing blueberries. There is no single set of 'best' properties for soil; it depends on where you are and what you expect of the soil in that place.

A related caution is that results apply directly only to the climatic and management conditions like those of the experimental site. This proviso, of course, applies to any long-term experiment. Such experiments are not intended to generate results that are then extrapolated elsewhere; but rather to generate *understanding* that can be extrapolated to other places. It is the *insights* that are applied to other sites; not the measured *observations*.

Future

One aim of the study was to define the relationship between indices of soil quality and plant yield. In the long run, however, a second objective may be more important; namely, to measure the changes in originally-diverse soils over several decades. In theory, the dynamic soil properties, such as organic matter, should eventually converge if the soils are maintained under similar climate and management practices. Initial observations, still preliminary, seem to confirm that hypothesis. The rate of convergence, however, depends on the turnover rate of the property in question. For example, decomposable organic matter (e.g., 'light fraction' organic matter, composed largely of partially-decayed plant residues) is apparently converging relatively quickly, whereas other organic matter, which has persisted in the soil already for centuries, will likely take a very long time to converge.

We intend soon to document, in detail, the changes in soil properties with time at the dryland site. Detailed analysis of samples from a 21-year time span (1990, 1997, 2004, and 2011) will be completed to determine rates of change, focusing mostly on various indices of soil organic matter amount and composition. A similar analysis may also be performed on the second site (originally under irrigation, but now under mixed grasses). These data sets may be particularly useful for evaluating and improving models of carbon turnover.

Soil samples from these sites are also available for other applications. For example, Major[5] used these soils to relate various soil properties to their reflectance values. We invite others with interest in this experiment to contact us for potential collaborative research opportunities.

Acknowledgements

We acknowledge with profound gratitude the producers and others who each generously donated several truckloads of soil to this experiment. As well, we thank technical staff (Lorna Selinger, Linda Kremenik, Yvonne Bruinsma, Ted Kaminski, and others) for their diligence in establishing and maintaining this experiment, despite its somewhat unusual challenges. Some of the findings from this study reported here are still preliminary, and await confirmation with future analyses, perhaps by future researchers.

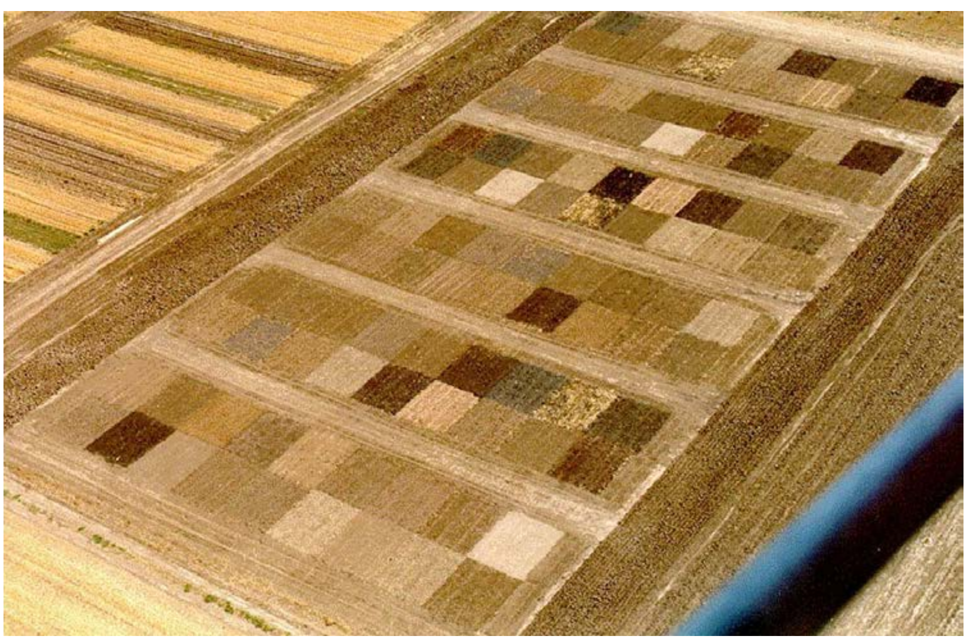

Figure 1. Aerial view of the long-term bioassay experiment (dryland site), shortly after establishment in 1990.

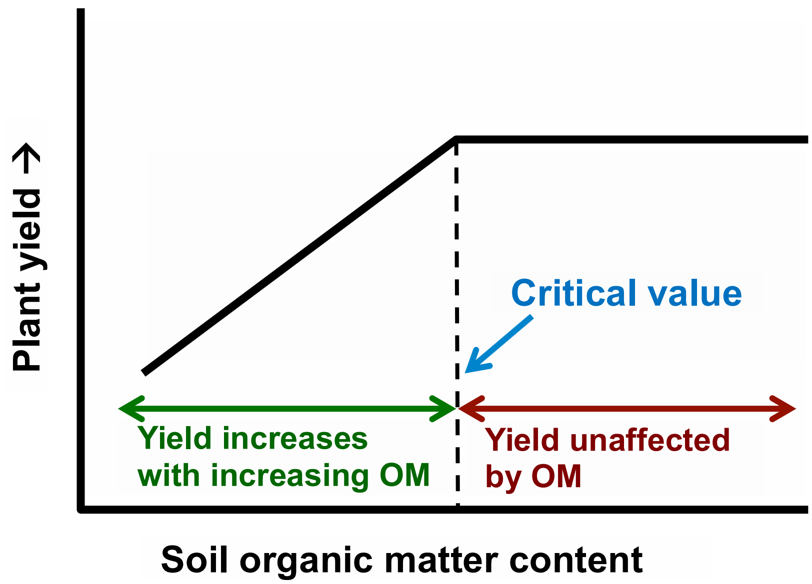

Figure 2. A hypothetical relationship between soil organic matter (OM) and plant yield, as suggested by our experiment. Yield increases with increasing organic matter content up to a critical value, beyond which yield stays at a plateau. There is likely no single critical value; it presumably varies with climate and other factors. For example, we might expect the critical value would increase (shift to the right) with higher rainfall than observed in our study. In many places, the current organic matter content may now be below the critical value, so that increases in organic matter would favor higher yields.

References

1. Bauer, A., and A.L. Black. 1994. Quantification of the effect of soil organic matter content on soil productivity. Soil Sci. Soc. Am. J. 58:185-193.
2. Chi, B.L., C.S. Bing, F. Walley and T. Yates. 2009. Topographic indices and yield variability in a rolling landscape of western Canada. Pedosphere 19:362-370.
3. Janzen, H.H., F.J. Larney, and B.M. Olson. 1992. Soil quality factors of problem soils in Alberta. pp. 17-28 In Proceedings of the 29th Annual Alberta Soil Science Workshop, Feb. 19 and 20, 1992, Lethbridge, Alberta.
4. Janzen, H.H. 2001. Soil science on the Canadian prairies – Peering into the future from a century ago. Can. J. Soil Sci. 81:489–503.
5. Major, D.J., H.H. Janzen, B.M. Olson and S.M. McGinn. 1992. Reflectance characteristics of southern Alberta soils. Can. J. Soil Sci. 72:611-615.
6. Noorbakhsh, S., J. Schoenau, B. Si, T. Zeleke, and P. Qian. 2008. Soil properties, yield, and landscape relationships in south-central Saskatchewan Canada. J. Plant Nutr. 31:539–556.
7. Olson, B.M., H.H. Janzen, F.J. Larney, and L.J. Selinger. 1996. A proposed method for measuring the effect of soil quality on productivity. Agron. J. 88:497-500.
8. Shutt, F.T. 1910. Western Prairie Soils: Their Nature and Composition. Department of Agriculture, Central Experimental Farm, Ottawa ON. Bulletin #6 Second Series.
9. Wright, R.J., D.G. Boyer, W.M. Winant, and H.D. Perry. 1990. The influence of soil factors on yield differences among landscape positions in an Appalachian cornfield. Soil Sci. 149:375-382.
10. Zvomuya, F., H.H. Janzen, F.J. Larney, and B.M. Olson. 2008. A long-term field bioassay of soil quality indicators in a semi-arid environment. Soil Sci. Soc. Am. J. 72:683-692.