Comment on "The Myth of Nitrogen Fertilization for Soil Carbon Sequestration", by S.A. Khan et al. in the Journal of Environmental Quality 36:1821–1832

Dear Editor,

In this paper, published in the Journal of Environmental Quality (2007), S.A. Khan and his co-authors have concluded that application of high rates of fertilizer nitrogen has caused the net loss of soil organic matter. This is a sensational claim, and it would be incredibly important if it was true, but the evidence presented in the paper does not unequivocally support such a conclusion. It is my belief that the authors have overlooked other, more plausible explanations for the changes in soil organic carbon that they have observed.

The main evidence presented by the authors is the decline in soil organic carbon (SOC) in the Morrow plots at the University of Illinois over the 51 yr period from 1955 to 2005. The greatest losses have occurred in the plots receiving the highest rates of NPK fertilizers, but the confounding factor, which has been ignored, is that the initial SOC contents in these plots were much higher than in the unamended or moderate fertilizer treatments. The graph of SOC concentrations over the past century clearly show that SOC was stable or increasing while livestock manure was being applied to these plots, and began to decline when this input of organic matter was replaced with mineral fertilizer. This is not unexpected, since SOC concentration is an equilibrium between carbon inputs and losses. Any changes to either side of the equation will result in a new equilibrium concentration being established. Other cases have been reported in the literature of a negative correlation between initial SOC concentration, and the change in SOC over time (VandenBygaart et al, 2002). It is much more likely that the decline in SOC is due to the change in the form of fertilizer than to the rate of fertilizer applied.

The authors also point to an extensive list of papers, which supposedly support their conclusion that nitrogen fertilizer is harmful to SOC. While this list does show a widespread decline in SOC concentrations, there is no evidence that the cause of this decline is nitrogen fertilizer. There is no consistent pattern of greater declines with higher nitrogen fertilizer rates, and the six studies (out of 25), which do include different nitrogen inputs show, no meaningful differences between the nitrogen treatments. The range in SOC change for the low N treatments was 0 to -21.9 Mg ha^{-1}, while the range for the high N treatments was +0.5 to -20.5 Mg ha^{-1}.

From the evidence presented in this paper, it would be fair to conclude that modern annual crop management systems are associated with declines in SOC concentrations, and that increased residue inputs from high nitrogen applications do not mitigate this decline as much as we might hope. It is not possible, however, to link the over-application of nitrogen fertilizers to the decline in SOC. It would be appropriate for the authors to restate their conclusions to reflect a more measured assessment of the evidence provided.

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Reply

We appreciate Mr. Reid's interest in our paper, and welcome the opportunity to further explain our findings that intensive use of N fertilizers in modern agriculture has not promoted soil C sequestration. These findings are neither sensational nor novel, but rest entirely on long-term data from the Morrow Plots and many other field studies throughout the world.

While acknowledging that "modern annual crop management systems" lead to a decline in soil organic C (SOC), Mr. Reid also maintains that heavy use of synthetic N fertilizers cannot be linked to this decline, despite the fact that these fertilizers are an integral part of modern crop-

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Table 1. Effect of N fertilization of the Morrow Plots on greenhouse gas emissions between 1955 and 2005.

Rotation†	Fertilizer treatment‡	Fertilizer N input	Greenhouse gas emission to the atmosphere: As CO_2 From SOC§	As CO_2 From fertilizer¶	As N_2O#	Total
		Mg ha^{-1}	Mg C ha^{-1}			
C-C	None	0	−3.7	0	0	−3.7
	NPK	10.8	0.3	13.0	13.7	27.0
C-O(S)	None	0	5.6	0	0	5.6
	NPK	5.7	5.2	6.8	7.2	19.2
C-O-H	None	0	11.4	0	0	11.4
	NPK	4.1	4.8	4.9	5.2	14.9

† C, corn; O, oats; S, soybean; H, alfalfa hay.

‡ As assigned to subplots NA and NB within each rotation [see Fig. 1 of Khan et al. (2007)]. Since 1967, the two-crop rotation has involved soybean instead of oats. NPK fertilization has supplied 168 [1955–1966] or 224 [since 1967] kg N ha^{-1} for corn (28 kg N ha^{-1} for oats), while maintaining Bray-1 P at 44 kg ha^{-1} and exchangeable K at 336 kg ha^{-1}.

§ SOC, soil organic C. Values as reported in Table 2 of Khan et al. (2007) for profile (0–46 cm) C storage, but with a sign change to represent assumed emission to the atmosphere.

¶ Estimated from fertilizer N input, assuming 1.2 Mg C Mg^{-1} N (Schlesinger, 2000) for estimation of CO_2 emissions during manufacture and transport of fertilizer N.

Calculated from fertilizer N input and expressed as a CO_2 equivalent, assuming 1% conversion of fertilizer N to N_2O-N (De Klein et al., 2006) and a global warming potential 296 times larger with a 100-yr horizon for N_2O than for CO_2 (Ramaswamy et al., 2001). Note that the 1% conversion factor is considerably more conservative than the 3–5% estimate by Crutzen et al. (2008).

ping practices. Such a view is at odds with a century of SOC changes reported for the Morrow Plots in Fig. 2 of Khan et al. (2007). Before the introduction of commercial NPK fertilization, SOC increased substantially with moldboard plowing, regardless of the initial level and without the return of aboveground residues, when corn was grown following oats or alfalfa, with a modest application of dairy manure that supplied approximately 20 to 30 kg N and 2 Mg C as an annual average per hectare. With modern management that began for these two subplots in 1967, the annual input of synthetic N averaged 116 to 161 kg ha^{-1}, as compared with 4.3 to 5.3 Mg C ha^{-1} supplied by the return of above- as well as belowground residues. According to the equilibrium concept mentioned by Mr. Reid, the increased C input should have caused an upward shift in SOC, rather than the dramatic decline that was actually observed. Clearly, C losses exceeded inputs, and this is most logically attributed to a massive increase in the input of N.

Besides data from the Morrow Plots, our paper utilizes a substantial collection of published literature from field trials around the world involving synthetic N fertilization, with emphasis in Table 3 on studies with initial (baseline) soil sampling. A decline usually occurred in SOC over time, despite the considerable range that existed in soil type and sampling depth, duration of the study period, quantity and quality of residue C inputs, tillage, and climatic regime. Given the confounding effects of such variability, a meaningful relationship would not be expected in quantifying the magnitude of SOC change on the basis of fertilizer N rate alone.

If agriculture is to play a role in reducing greenhouse gas emissions, not only is there a need to increase SOC storage, but this must be accomplished with a full accounting of C input costs. These costs are by no means negligible for the energy-intensive "modern annual crop management systems" referred to by Mr. Reid. As noted in our paper with reference to Schlesinger (2000), there is a C cost associated with the manufacture, transport, and application of N fertilizers, which necessarily increases with the N rate applied, as does the cost associated with N_2O emission (De Klein et al., 2006; Crutzen et al., 2008). A comprehensive accounting would include C costs associated with planting, tillage, harvesting, grain transport, pesticide synthesis and application, P and K fertilization, etc. Table 1 incorporates both of the latter costs in estimating net greenhouse gas emissions with and without the lower N rate applied to Morrow Plots that had been unfertilized before 1955. According to these estimates, not only did NPK fertilization fail to reverse the SOC decline, the fertilizer inputs had a considerable atmospheric impact, especially with regard to continuous corn or the corn–soybean rotation that currently dominates the USA Corn Belt. Under these circumstances, it would be appropriate to conclude that N fertilization is of no benefit for soil C sequestration but does contribute to CO_2 enrichment of air.

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