The Essential Role of Soil Organic Matter in Crop Production and the Efficient use of Nitrogen and Phosphorus

By Johnny Johnston

The role of soil organic matter (SOM) in supporting the nutrient requirements of high crop yields is fundamental, especially as crop yield potential continues to improve. Lessons on N and P interactions with SOM and its support of high crop yields are well illustrated here through examples gleaned from long-term research conducted at Rothamsted.

A first example of the contribution of SOM towards enhancing crop productivity is provided here through use of data from the Hoosfield Continuous Barley experiment at Rothamsted. Started in 1852 on a silty clay loam soil, the Hoosfield site received annual application of NPK fertilizers, or farmyard manure (FYM) at 35 t/ha, which produced soils that now have 1.74 and 6.16% SOM, respectively. Each year since 1968, four amounts of fertilizer N (0, 48, 96, and 144 kg N/ha) are applied to these soils. Beginning in the mid 1970s, **Figure 1** plots changes in grain yield of three successive cultivars of spring barley, each with higher yield potential than its predecessor. On the soil with lower SOM, the crop responds to N and there is little difference in maximum yield of the three cultivars in the three periods. On soil with more SOM, the crop responds only a little to fertilizer N, but as the yield potential of the crop has increased, the maximum yield on this soil has increased—as has the benefit from having more SOM. The difference in maximum grain yield on the two soils is now more than 2.5 t/ha.

Similarly, on the Broadbalk winter wheat experiment, soils treated with fertilizers or FYM (35 t/ha each year) since 1843 now contain 1.93 and 4.87% SOM, respectively. Different amounts of N have always been tested with PK fertilizers and the resulting yields have compared with those given by FYM alone. In many years before 1967, grain yields with FYM were slightly better than with fertilizers (Garner and Dyke, 1969), but the yield increase due to FYM for winter wheat was not as large as that with spring barley, probably because winter wheat has a longer growing season in which to make a root system. Since 1968, when short-strawed cultivars were introduced with improved grain-to-straw ratios and higher yield potentials, yields have only been larger on FYM-treated soil if an additional 96 kg N/ha is given as fertilizer. Interestingly, when cv. Hereward began to be grown at Broadbalk in 1996, the addition of 96 kg N/ha with FYM no longer gave a larger yield than the optimum NPK fertilizer application (Johnston et al., 2009). Since 2005 it has been necessary to add 144 kg N/ha with FYM to give slightly larger yields than with fertilizers. It would seem that the available N from 35 t/ha FYM, and that mineralized from the accumulated SOM, is not sufficient to give maximum yields of a cultivar of winter wheat with a large yield potential. It would be interesting to speculate why this is so.

Common abbreviations and notes: N = nitrogen; P = phosphorus; C = carbon.

Soil Organic Matter and Nitrogen Interactions

At the present time there is considerable interest in the efficient use of N in agriculture. This arises not only because the different forms and pathways by which N can be lost from soil can have adverse environmental impact, but also because such losses are a direct cost to growers. There is much evidence to show that N is used more efficiently on soils with more organic matter, and presumably a better structure, so that roots explore the soil more effectively to find nutrients.

On a sandy loam soil with two levels of SOM, potatoes, spring barley, winter wheat, and winter barley have been grown in different years, each crop given four appropriate amounts of N (**Figure 2**).

Yields of the spring sown crops, potatoes and barley, were

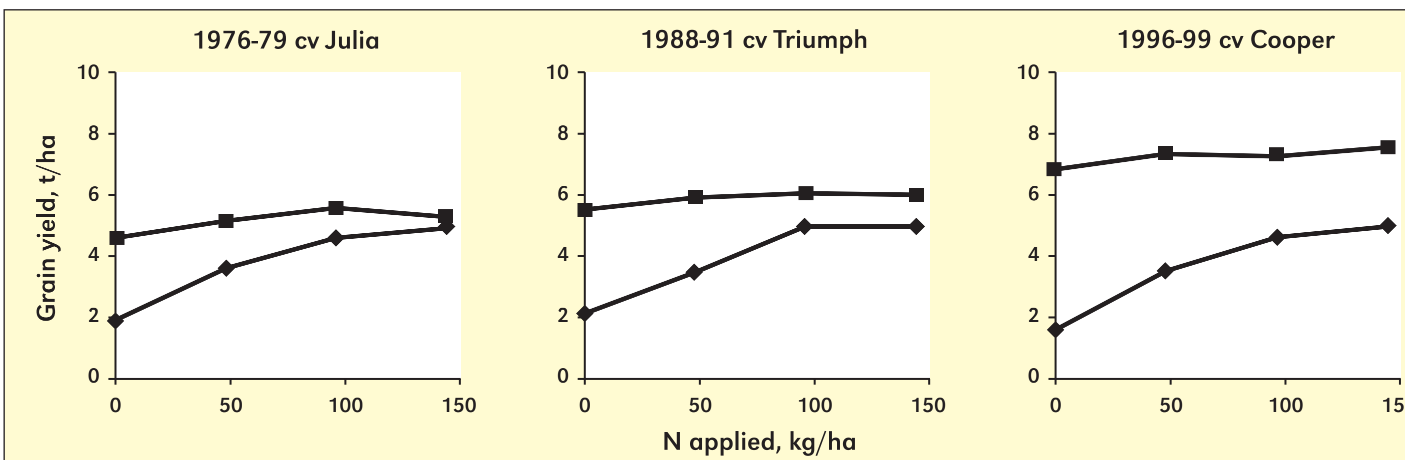

Figure 1. Grain yield response to applied N from three spring barley cultivars with increasing yield potential (left to right) grown on two soils with 1.74 (◆) or 6.16 (■) % SOM, Hoosfield Continuous Barley experiment, Rothamsted.

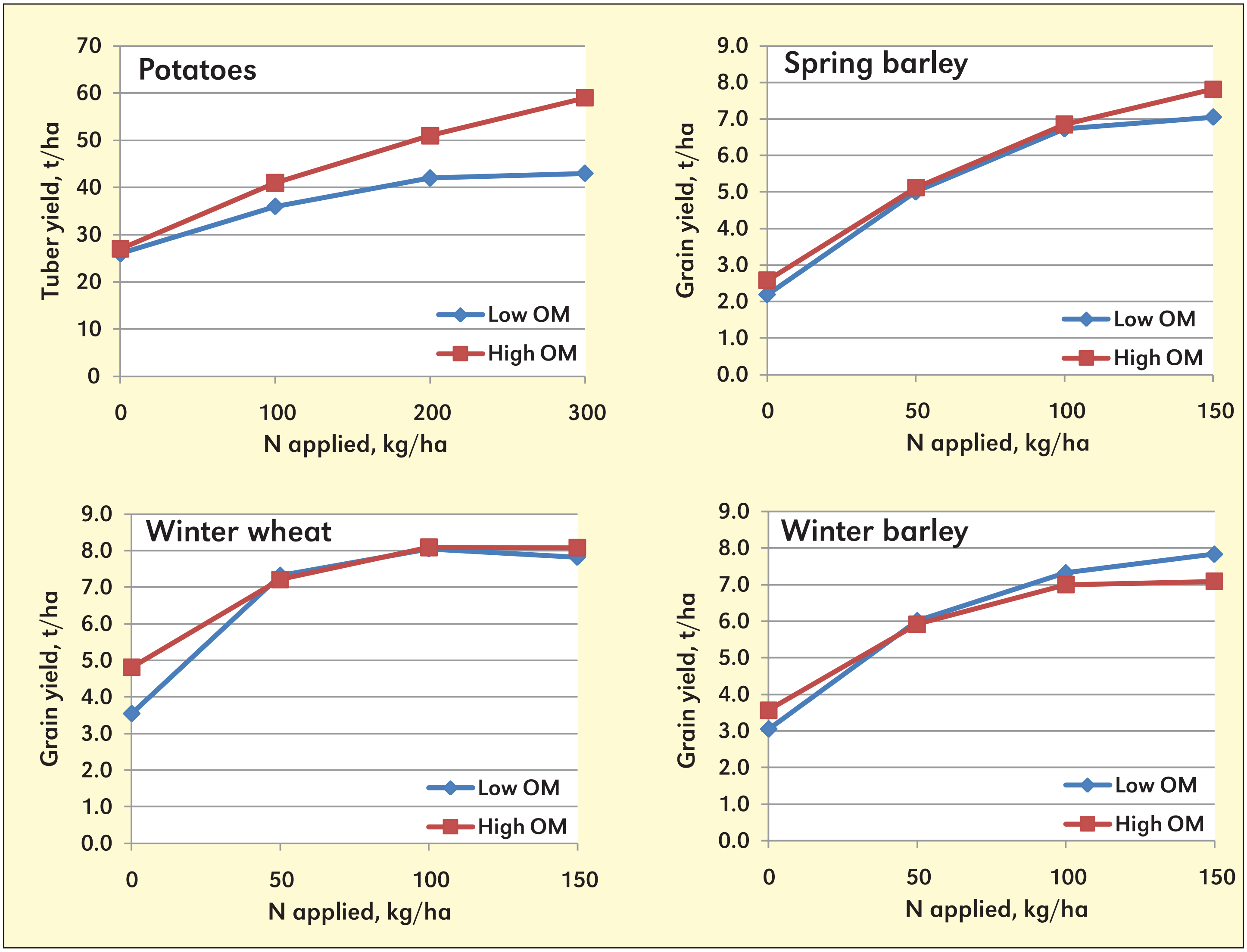

Figure 2. Yield response to applied N by spring and winter crops grown on a sandy loam soil with two levels of SOM, 1.3 and 3.4%, respectively.

always larger on the soil with more SOM irrespective of the amount of N applied, and the recovery of the applied N was greater where the yields were larger. A better soil structure with more SOM allowed for quicker root development and better exploration of the soil mass for nutrients. At each amount of applied N, the yields of the winter sown cereals, with a longer growing period than a spring-sown crop, were largely independent of SOM, probably because these autumn-sown crops had time to develop an adequate root system on the soil with less SOM.

In another experiment on a sandy loam soil, the effects of various organic amendments on SOM and yields of arable crops have been tested since 1964 with two periods of organic additions (the "treatment" period) and two periods of arable "test" cropping (Johnston et al., 2009). Annual organic treatments that were common to both periods of addition included incorporating straw (7.5 t/ha dry matter), applying FYM (50 t/ha fresh material) and growing and then incorporating a grass/clover ley (temporary pasture) before growing arable "test" crops to measure the effects of any additional SOM built up during the two "treatment" periods.

In 1986, C in the top 23 cm was 0.65% without organic addition—about the equilibrium level for this soil and treatment. The organic additions increased it to 0.85% with added straw, 1.06% with FYM, and 0.90% following the incorporation of an 8-year grass/clover ley. The yields of potatoes (in 1988 and 1989) and winter wheat (in 1987 and 1988), each testing six amounts of N, are compared with those on soils without extra organic matter addition in **Figure 3**. Yields were always smallest on soil with least SOM and generally largest on soils ploughed out from the grass/clover ley. In all comparisons, less N was needed to achieve optimum yield on soil with more SOM.

There are two interesting features in these results. First, in **Figure 3a**, the largest winter wheat response to the maximum amount of N tested was on the FYM treatment—an effect similar to that on the Broadbalk experiment discussed earlier, and perhaps explained for the same reason. Second, following the ploughed-in grass/clover ley, the largest yields were with the second increment of N tested, suggesting that there could have been some beneficial effect late in the growing season from N mineralized from the N-rich ley residues ploughed-in the previous autumn. If this mineralized N is lower down in the soil profile, where roots are actively taking up nutrients, then such a beneficial effect would be difficult to mimic with fertilizer N applied on the soil surface.

Two further comments about these results; first, although best yields followed the grass/clover ley, having a ley for 3 years must be economically viable within the whole farm budget. Second, there was continued beneficial effects from straw incorporation, one of the few methods available to many farmers for slightly increasing or maintaining SOM, and perhaps preventing SOM decline.

Soil Organic Matter and Phosphorus Interactions

In addition to important interactions between SOM and the response to N, there are equally important interactions between SOM and plant-available P in soil. In an experiment on a silty clay loam soil, known to be difficult to cultivate, especially in spring, plots were established over a 12-year period with two levels of SOM, 1.5% (the arable plots) and 2.4% (the grass plots), and 24 levels of Olsen-P at each level of SOM. After the 12-year preparatory period, potatoes, sugar beet, and spring barley were each grown twice in rotation in 3 years. The 2-year average yield of each crop was plotted against Olsen-P, and the response curve fitted statistically to determine maximum yield and Olsen-P associated with 95% of the maximum yield (**Table 1**).

Table 1. Crop yield and Olsen-P associated with 95% of the maximum yield determined by plotting the 2-year average crop yields against Olsen-P.

Crop yield	Soil organic matter, %	Yield at 95% maximum, t/ha	Olsen-P associated with 95% yield, mg/kg	R^2
		Field experiment		
Spring barley grain, t/ha	2.4	5.00	16	0.83
	1.5	4.45	45	0.46
Potatoes tubers, t/ha	2.4	44.7	17	0.89
	1.5	44.1	61	0.72
Sugar beet sugar, t/ha	2.4	6.58	18	0.87
	1.5	6.56	32	0.61
		Pot experiment		
Grass dry matter, g/pot	2.4	6.46	23	0.96
	1.5	6.51	25	0.82

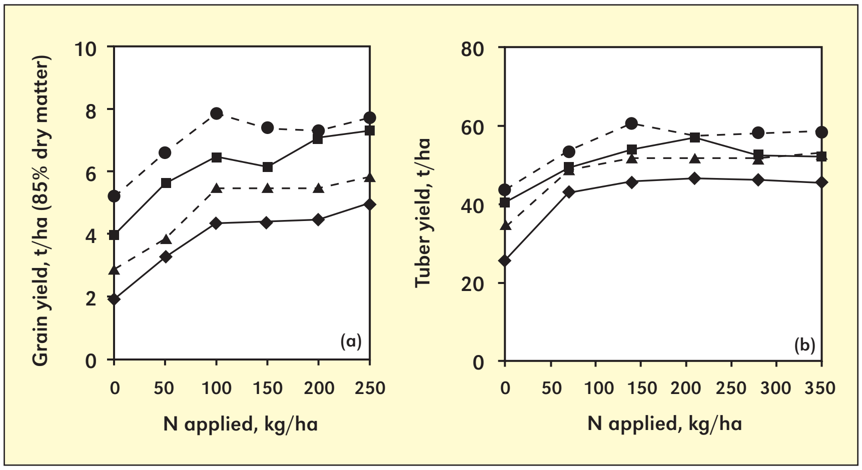

Figure 3. Yield response to N rate for winter wheat in 1987/88 (a) and potatoes in 1988/89 (b) after periods of various organic treatments (see text). Treatment and % SOM: No organic amendment, 0.65% SOM (◆); incorporating straw, 0.85% SOM (▲); adding FYM, 1.06% SOM (■); incorporating a grass/clover ley, 0.90% SOM (●).

The 95% yield of spring barley was appreciably smaller on soil with low SOM compared to that on soil with high SOM, but potatoes and sugar beet gave similar yields on both soils because better seedbeds could be prepared for these two crops sown later than spring barley. Of great importance, however, the level of Olsen-P associated with the 95% yield was much lower on soil with more SOM. The effect of SOM was to improve soil structure so that roots could grow more freely and explore the soil more thoroughly to find plant-available P.

Subsequently, soil samples from all 48 plots (two levels of SOM x 24 levels Olsen-P) were cropped with ryegrass under uniform conditions in the glasshouse. The cumulative yields from four harvests were plotted against Olsen-P and the response curves on soil with the two levels of SOM were not visually different. The 95% yields were virtually the same as were the Olsen-P levels associated with these yields (**Table 1**) strongly suggesting that soil structure in the field was the explanation for the large differences in Olsen-P associated with the 95% yields.

Summary

It is not easy to increase SOM in many arable cropping systems unless it is possible to add large amounts of organic materials. However, every attempt should be made to conserve and increase SOM wherever possible because it improves soil structure and thus the ability of plant roots to grow through the soil to find the nutrients required to optimize growth and yield. This is especially so in relation to the acquisition of N and P and thus their efficient use in agriculture. BC

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References

Garner, H.V. and G.V. Dyke. 1969. Rothamsted Experimental Station Report for 1968, Part 2, 26-49.

Johnston, A.E., P.R. Poulton, and K. Coleman. 2009. Advances in Agronomy 101, 1-57.