Guidelines for organic amendment experiments to enable attribution of yield to plant nutrition or soil amelioration

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Abstract
Organic amendments such as manures, composts and plant residues are often used as alternatives to inorganic fertilisers or to ameliorate physicochemical soil constraints. Crop yield responses to the application of organic amendments could be due to plant nutrients contained in the amendment, the amelioration of (sub)soil constraints, or some combination of both factors. However, if experiments are designed incorrectly these factors can be confounded, leading to difficulties in accurately ascribing yield responses to nutrition or amelioration. We suggest guidelines for design, conduct and analysis of organic amendment experiments which will allow the correct attribution of yield responses. These include: identifying genuine soil constraints, selecting proper control treatments, and using appropriate sampling protocols to assess treatment differences.

Key Words
Organic matter, fertiliser, soil constraints, experimental design.

Introduction:
Soil organic matter is a critical component of productive soils because it influences a wide range of physical, chemical and biological properties including the formation and stabilization of soil aggregates, nutrient cycling, water retention, disease suppression, pH buffering and cation exchange capacity (Murphy 2015). Consequently, organic matter is important from an agronomic perspective because it has the potential to influence crop yields via any of these processes (Oelofse *et al.* 2015). Interest is growing regarding the use of strategically-placed organic amendments such as animal manures and plant residues for their potential to ameliorate physicochemical constraints and therefore increase crop productivity on compaction-prone sandy soils with low fertility (Collis 2018; Haskins *et al.* 2018), dispersive, sodic clay subsoils (Baxter 2017; Collis 2017) and acidic subsoils (Li and Burns, 2017).

However, there are multiple factors that can contribute to crop yield responses to organic amendments. Organic amendments can directly affect yields via their fertiliser effect on the plant, or indirectly affect yields via their effects on soil carbon, structure, biology and so on (Edmeades 2003; van Zwieten 2018). Therefore, there is a need to separate the 'organic matter effect' of these amendments from other confounding variables such as improved plant nutrition (Dawe *et al.* 2003; Hijbeek *et al.* 2018; Schjønning *et al.* 2018). The nutrients contained within organic amendments and the associated direct fertiliser response in the crop is frequently overlooked, and it is often impossible to separate these nutrient effects from other non-nutrient effects of the organic matter itself due to poor experimental design. Properly designed and monitored experiments need to be conducted on genuinely constraining soils in order to accurately ascribe crop yield responses to amelioration of soil physicochemical properties or some other factor such as increased nutrient supply.

Guidelines for the design and evaluation of organic amendment experiments
Identification of a constraint to crop yield at the field site
Prior to carrying out any soil amelioration practice, it is necessary to determine that there is a genuine and measurable constraint to crop yield at the field site. A (sub)soil constraint to root growth must exist, and its impact on plant growth must be known, if yield increases from an amelioration intervention are to be attributed to the alleviation of one or more constraints. These constraints may be physical (e.g. high bulk density, poor infiltration), chemical (e.g. sodicity, alkalinity) or biological (e.g. low organic matter) and may occur in isolation or involve multiple interacting constraints. A soil pit or intact cores may be required to observe the soil profile and characterise these properties.

If the (sub)soil constraint is genuinely limiting plant growth, then crop rooting depth and soil water extraction will be negatively affected (Figure 1). We recommend assessing this using the method of soil characterisation outlined by Burk and Dalgliesh (2013), whereby soil water extraction by an otherwise healthy and unstressed crop growing on a constrained soil is measured. This procedure can be used to determine the severity of the soil constraint prior to treatment, as well as assess the degree to which a particular soil management intervention has affected the ability of the crop to extract water.

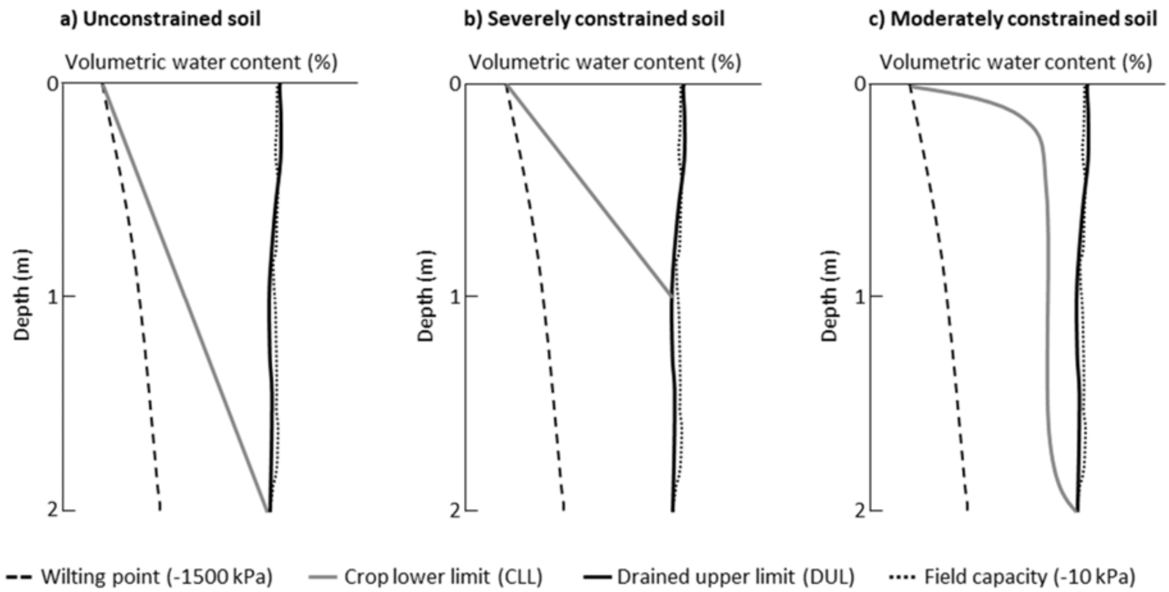

Figure 1. Representation of soil water profiles in an unconstrained soil (a) and in a constrained soil where root growth and water uptake is completely stopped (b) or restricted (c). Adapted from Celestina *et al.* (2019).

Appropriate experimental design for yield attribution

Because organic amendments can contain large amounts of macro- and micro-nutrients, experiments must include appropriate treatments to control for this increased nutrient supply. Without the proper control treatments, it is impossible to determine whether yield responses are due to plant nutrition or soil amelioration because these effects will be confounded. Therefore, the application of the organic amendment needs to be compared to a synthetic fertiliser treatment where the same rate of total nutrients is provided to the plant (Table 1). This synthetic fertiliser treatment is necessary to be able to separate the nutrient effect of the organic amendment (i.e. improved soil fertility) from the non-nutrient effects that are due to its carbon and biological components (e.g. improved soil aggregation, increased water holding capacity). If the organic amendment is providing some benefit to the crop over and above the direct fertiliser effect of the nutrients, then that treatment should increase crop yields more than just synthetic fertiliser alone relative to a nil amendment control.

Table 1. Amendment treatments required to separate nutrient- and non-nutrient effects of organic amendments on yield. Adapted from Celestina *et al.* (2019).

Amendment treatment		
No amendment	Organic amendment	Synthetic fertiliser

In some experiments, organic amendments are incorporated into the subsoil to directly target constraints that occur below the topsoil layer. In these experiments, additional treatments are required to separate the nutrient effects of the amendment from the effects of placement depth. In addition to the synthetic fertiliser control described above, these experiments also require tillage control treatments in which the same rate of organic amendment and synthetic fertiliser is applied to both the soil surface and the subsoil (Table 2). These treatments allow attribution of yield increases to either plant nutrition or subsoil amelioration by separating the nutrient and non-nutrient effects of the amendment and the effects of surface broadcasting versus deep tillage. If the deep placement of organic amendments is ameliorating physicochemical constraints in the subsoil, then that treatment should increase crop yields over and above those achieved by surface broadcasting the same amendment, or with synthetic fertiliser placed on the surface or in the subsoil.

Table 2. Tillage and amendment treatments required to separate nutrient and non-nutrient effects of subsoil-placed organic amendments on yield. Adapted from Celestina *et al.* (2019).

		Amendment treatment		
		No amendment	**Organic amendment**	**Synthetic fertiliser**
Tillage treatment	**No tillage/surface broadcast**	Full control	Surface applied control	Surface applied nutrient control
	Deep tillage	Tillage control	Subsurface amendment	Deep nutrient control

There are difficulties with experiments such as these due to variation in the content, release rates and availability of nutrients between different types of amendments and different methods of application to the soil. In addition, high application rates can result in nutrient toxicities or deficiencies or losses to the environment. Due to these uncontrollable variables, field experiments will inevitably always be confounded to some degree. Wherever possible, researchers should apply fertilisers using foliar or split applications and use slow-release products to better match nutrient supply and demand through the growing season.

Appropriate sampling protocols to assess grain yield responses

Depending on the method used to apply amendments to the soil, spatially variable distributions of nutrients can occur. For example, surface broadcasting will result in an even spread of the organic amendment across the soil surface, whereas subsoil manuring concentrates the amendment in discrete bands 30-40 cm deep and 80 cm apart (Gill *et al.* 2008) (Figure 2a). Crops growing on soil treated with subsoil manuring will be sown over amended or un-amended soil, so the method used to estimate grain yield in these experiments must account for this spatial heterogeneity to prevent under- or over-estimation of yield. The appropriate sampling protocol in the subsoil manuring example described above would be to ensure that an equal ratio of amended to un-amended crop rows are collected for analysis by harvesting the repeated unit. In this example, multiples of 80 cm-wide sections of the treated plot are sampled to reflect the 80 cm-wide rip lines (Figure 2b). In contrast, where amendments are surface broadcast, all crop rows will be sown on top of amended soil and are therefore subject to the same treatment. In this scenario, normal plot sampling procedures can be followed. In experiments where multiple methods of amendment applications are used, the sampling protocol must be consistent across all treatments and will be determined by the method used to sample the spatially heterogenous treatment.

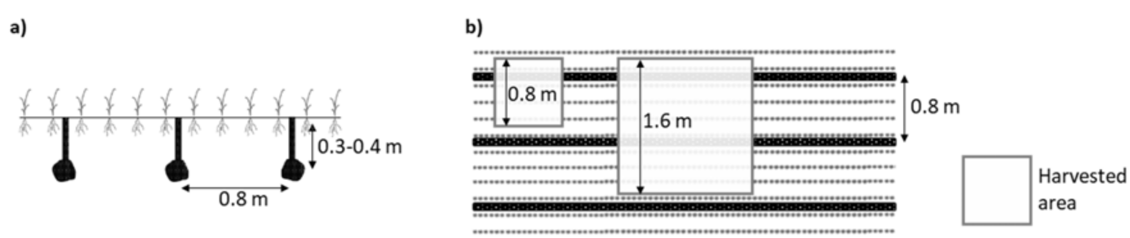

Figure 2. Top and side view of subsoil manuring plots showing the spatially variable distribution of amendment (a) and the appropriate sampling strategy to assess yield (b). Adapted from Celestina *et al.* (2019).

Additional measurements to separate plant nutrition and soil amelioration effects

In addition to assessing grain yield responses, a range of other measurements can also be made to assist in attributing yield responses to plant nutrition or soil amelioration. These will depend on the specific research question being asked but may include measurements of plant tissue nutrient content at critical growth stages, crop water use during the growing season, or soil physical properties at intervals after treatment.

Conclusion

In order to attribute crop yield responses to organic amendments to nutrition, soil physical or chemical improvement or some other factor, field experiments on the use of organic amendments must:

1. Identify a genuine and measurable constraint to crop yields at the experimental site;
2. Incorporate proper control treatments to account for nutrient and tillage effects;
3. Assess treatment differences using appropriate sampling protocols for crop yield that adequately account for spatial variation of application methods; and,
4. Carry out appropriate soil and plant analyses to elucidate mechanisms responsible for yield responses.

References

Baxter N (2017) Trials dig deep to ameliorate sodic soils. GRDC GroundCover Magazine Issue 130, September–October 2017. GRDC, Canberra, ACT.

Burk L, Dalgliesh N (2013) 'Estimating Plant Available Water Capacity.' GRDC, Canberra.

Celestina C, Hunt JR, Sale PWG, Franks AE (2019) Attribution of crop yield responses to application of organic amendments: a critical review. Soil & Tillage Research 186, 135–145.

Collis C (2017) New project probes subsoil constraints. GRDC GroundCover Magazine Issue 131, November–December 2017. GRDC, Canberra.

Collis C (2018). Amelioration trials spur practice change. GRDC GroundCover Magazine Issue 135, July–August 2018. GRDC, Canberra.

Dawe D, Dobermann A, Ladha JK, Yadav RL, Bao L, Gupta RK, Lal P, Panaullah G, Sariam O, Singh Y, Swarup A, Zhen QX (2003) Do organic amendments improve yield trends and profitability in intensive rice systems? Field Crops Research 83, 191–213.

Edmeades DC (2003) The long-term effects of manures and fertilisers on soil productivity and quality: a review. Nutrient Cycling in Agroecosystems 66, 165–180.

Gill JS, Sale PWG, Tang C (2008) Amelioration of dense sodic subsoil using organic amendments increases wheat yield more than using gypsum in a high rainfall zone of southern Australia. Field Crops Research 107, 265–275.

Haskins B, Whitworth R, Kookana R, Macdonald L (2018) Improving productivity on low fertility (sandy) soils. Proceedings of the 2018 GRDC Grains Research Update, Wagga Wagga NSW, 13 February 2018.

Hijbeek R, van Ittersum MK, ten Berge H, Whitmore AP (2018) Evidence review indicates rethink on the impacts of organic inputs and soil organic matter on crop yield. Proceedings 826 of the International Fertiliser Society Conference, Cambridge UK, 7 December 2018.

Li G, Burns H (2017) Early measure of ameliorants to neutralise subsoil acidity. GRDC GroundCover Magazine Issue 129, July–August 2017. GRDC, Canberra.

Murphy BW (2015) Impact of soil organic matter on soil properties – a review with emphasis on Australian soils. Soil Research 53, 605–635.

Oelofse M, Markussen B, Knudsen L, Schelde K, Olesen JE, Jensen LS, Bruun S (2015) Do soil organic carbon levels affect potential yields and nitrogen use efficiency? An analysis of winter wheat and spring barley field trials. European Journal of Agronomy 66, 62–73.

Schjønning P, Jensen JL, Bruun S, Jensen LS, Christensen BT, Munkholm LJ, Oelofse M, Baby S, Knudsen L (2018) The role of soil organic matter for maintaining crop yields: evidence for a renewed conceptual basis. Advances in Agronomy 150, 35–79.

van Zwieten L (2018) The long-term role of organic amendments in addressing soil constraints to production. Nutrient Cycling in Agroecosystems 111, 99–102.