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Influence of clay clod size and number for organic carbon distribution in sandy soil with clay addition

Amanda Schapel[a,b,*], Petra Marschner[a], Jock Churchman[a]

[a] School of Agriculture, Food and Wine, The University of Adelaide, Glen Osmond 5064, Australia
[b] Primary Industries and Regions SA, Rural Solutions SA, PO Box 245, Nuriootpa 5355, Australia

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ABSTRACT

In agricultural soils, subsoil clay addition to sand has the potential to improve carbon sequestration by increasing soil organic carbon (OC) concentration through adsorption and occlusion. However, the factors influencing increased OC in these engineered soils are poorly understood. The addition of subsoil clay creates clods of different sizes, from a few mm up to 200 mm or more in diameter. This study assessed the i) size, number and vertical distribution of clods and OC at two clay-modified field sites and ii) effect of clod size and properties on OC in incubation experiments. The hypotheses were that smaller clods would increase and stabilise OC more than larger clods and that an even distribution of clods throughout the depth of modification will increase OC stock compared to patchy distribution. Two field sites with differing clay modification method, delved and spaded, were studied. Soil was excavated from a 30 cm quadrat in 10 cm increments down the profile, sieved into clod sizes and mass with clod number and OC concentration determined. Delving elevated clay from 40 to 60 cm depth and created few clods, which were poorly distributed in the depth of modification. Spading mixed clay from 20 to 30 cm below the soil surface and created many, smaller sized clods, which were more evenly distributed within the 0–30 cm modification depth. OC concentration was highest in the smallest clods, particularly at the soil surface. OC stock increased with clod number. Clods collected from the two field sites were further used in incubation experiments to determine the effect of clod size and properties (clay and iron concentration) on the accumulation and protection of OC. Clods (2–6 and 6–20 mm) were added to sand at 80 mg clay g^{-1} sand and incubated 300 or 420 days at optimal moisture conditions with monthly wheat residue addition in the accumulation experiment. Smaller clods (2–6 mm) accumulated OC at a higher rate and offered greater protection from decomposition by microbes than larger clods (6–20 mm). These results support our hypotheses that smaller clods and even vertical distribution is important to increase OC. Furthermore, clod number was a critical factor in increasing OC content. We conclude that in clay-modified soils the addition of many, smaller sized clods distributed throughout the depth of modification can improve OC content.

1. Introduction

Carbon sequestration in agricultural soils provides an opportunity to offset greenhouse gas emissions (Lal, 2004). Increased organic carbon (OC) concentration has been reported to improve soil health, fertility, structure, water-holding capacity and productivity (Chan et al., 2003; Baldock and Skjemstad, 1999). Sanderman et al. (2010) suggested that in Australia, conversion of native land for agriculture has resulted in 40 to 60% loss of soil OC. Furthermore, improved management of cropland, for example improved crop rotation, adoption of no-till or stubble retention, conversion of annual to perennial pasture species, can increase carbon at rates of 0.2–0.3 Mg C ha^{-1} y^{-1} compared to conventional management. However, there are a number of factors that alone or in combination will affect the total amount and distribution of OC in the soil profile including climate, topography, soil biota and soil type (Baldock and Skjemstad, 2000). The amount of OC stored varies among soil types (Hoyle et al., 2013) and is strongly influenced by clay concentration (Rakhsh et al., 2017). Sandy soils have low capacity to physically protect OC from microbial breakdown (Six et al., 1999). In contrast, clay soils can store large amounts of OC due to binding of OC to clay particles which protects it from decomposition by microbes. The addition of subsoil clay to sand (clay modification) can increase OC accumulation through binding to clay surfaces (Baldock, 2007; Skjemstad et al., 1993) and by occlusion in micro-aggregates formed by clay (Tisdall and Oades, 1982). The OC concentration of subsoil clay is generally lower than that of a similar textured topsoil due to lower OC

* Corresponding author at: Primary Industries and Regions SA, Rural Solutions SA, PO Box 245, Nuriootpa 5355, Australia.
E-mail address: Amanda.Schapel@sa.gov.au (A. Schapel).

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inputs (Rumpel and Kögel-Knabner, 2011). Therefore, subsoil clay may have a high potential for stabilisation of OC as saturation of the mineral particles is unlikely to have occurred (Lützow et al., 2006). Stabilisation of OC depends on clay mineralogy, sesquioxide, carbonate concentration and formation of stable micro-aggregates (Denef et al., 2001a, 2001b; Fernandez-Ugalde et al., 2011; Lützow et al., 2006; Rakhsh et al., 2017; Saidy et al., 2012; Six et al., 2004) and time (Hoyle, 2013).

Subsoil clay addition to sand may increase OC input from improved plant growth resulting from increased nutrient and water retention. Field investigations of clay-modified soils have reported increased OC (Churchman et al., 2014; Hall et al., 2010; Schapel et al., 2017; Tonkin et al., 2012), increased yield (Davenport et al., 2011; Hall et al., 2010; Noble et al., 2001; Ozhan et al., 2008), nutrient availability (Bailey and Hughes, 2012; Hall et al., 2010) and root growth (Bailey et al., 2010; Hall et al., 1994), reduced water repellence (Cann, 2000; Harper et al., 2000; Ma'shum et al., 1989; McKissock et al., 2000; Ward and Oades, 1993) and saturated hydraulic conductivity (Betti et al., 2016). The increase in OC input and the greater capacity for adsorption and occlusion of clay-amended sandy soils is likely to increase OC storage. However, little is known about how long it will take for the OC increase to occur.

Sands cover 900 million hectares (Mha) of the world's surface (FAO/UNESCO, 1995). In Australia, there are approximately 5 Mha of sands used for agriculture and suitable for clay addition (Harper, 2012) with an estimated 0.16 Mha already clay modified in southern and Western Australia (Churchman et al., 2014). In South Australia, the most common methods of clay modification are addition of subsoil clay to the surface of the sand (spreading) or elevation of subsoil clay (delving, spading) throughout the soil profile (Fig. 1). Selection of the appropriate modification method is determined by the depth to clay-rich subsoil (Davenport et al., 2011) and the machinery available. Clay spreading is the only available option for deep sands where clay-rich subsoil is at > 60 cm depth. Clay-rich subsoil is excavated from a nearby pit, spread to the sand surface and then incorporated. Delving is used where clay-rich subsoil is present within 30–60 cm depth (Desbiolles et al., 1997), where specially designed tynes elevate the clay-rich subsoil into the sand above. After delving, elevated clay clods are spread using bars, dragging clay from delve line into the area between delve lines (0.7–2 m depending on machine design) and then incorporated. The area between delve lines is modified to the depth of incorporation but below this depth, the sand remains undisturbed. Spading can be used as a clay modification method where clay-rich subsoil is within 30–40 cm depth. Clay is elevated and incorporated in one pass using specially designed 'spades' spaced 0.35 m apart on a rotary axle. While delving creates distinct areas of modification, delve lines and area between the delve line, clay spreading and spading result in a more uniform distribution of subsoil clay clods to the depth of incorporation. All clay modification methods result in a mix of clay clods ranging in size from a few mm up to > 200 mm (Schapel, 2017 pers. obs) in a sand matrix.

In agricultural soil under dryland cropping, Schapel et al. (2017) reported increased OC stock up to 22 $t ha^{-1}$ (average 10.9 $t ha^{-1}$) in the surface 30 cm, 3 to 9 years after clay modification compared to unmodified sands. OC stock increase was found to be influenced by clay modification method, and dependent on clay concentration, depth of incorporation (distribution of clay clods) and possibly clod size. Spading with added organic matter gave the highest increase compared to the unmodified sand. Organic matter plays a critical role in the soil, creating aggregates of soil particles, stabilising structure, increasing water infiltration and overall water holding capacity, storing and releasing nutrients; improving cation exchange and buffering capacity (Baldock, 2007; Hoyle, 2013).

In an incubation experiment, Rakhsh et al. (2017) assessed the effect of subsoil clay addition to sand after plant residue addition. After 184 days, they found higher OC concentration associated with finely ground clay (< 2 mm) mixed with sand than in sand alone. In clay-amended sand 45 days after residue addition, Tahir and Marschner (2016) found no clear difference between OC concentration in 1 mm compared to 3 mm clods. The lack of difference between clods may be because size and thus surface area were not sufficiently different. Nevertheless, soil respiration was lower in 3 mm than 1 mm clods, indicating reduced OC decomposition in the larger clod size.

The factors influencing OC in these engineered soils are poorly understood and little is known about the effect of clod size and properties on OC in the field. This study aimed to determine the i) size, number and vertical distribution of artificially created clods and OC at

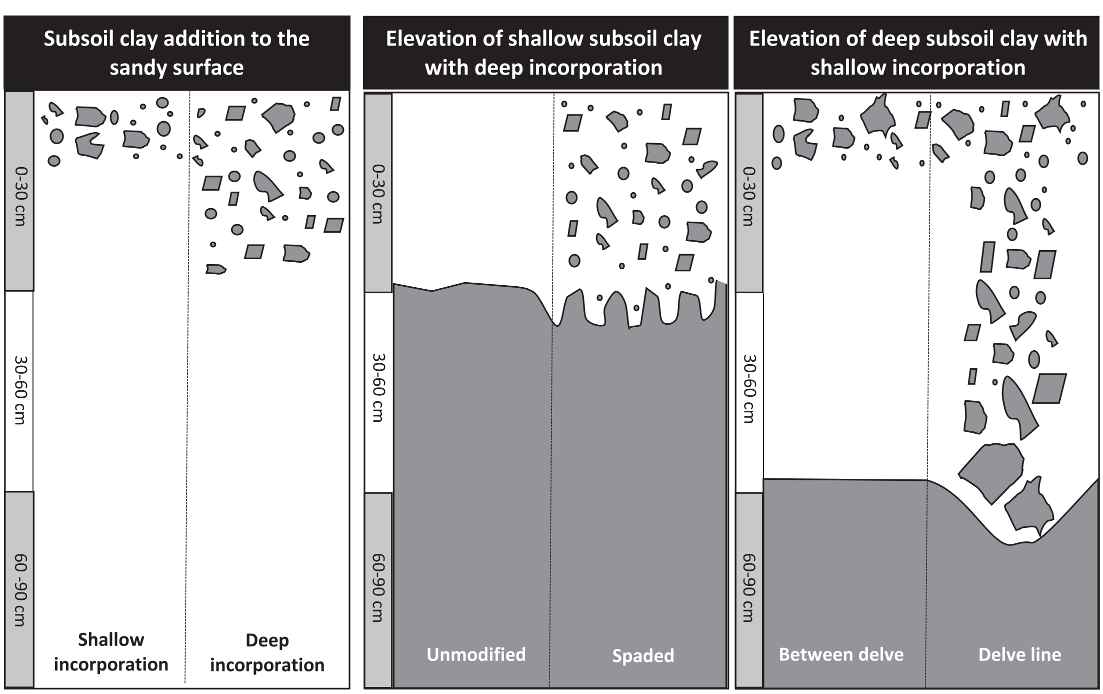

Fig. 1. Schematic diagram (not to scale) of distribution of clay clods in the soil profile with clay addition to surface or elevation from subsoil.