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Radical soil management for Australia: A rejuvenation process

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ABSTRACT

Particularly in the Australian context, this concept paper argues that much of the continent has highly weathered soil of great antiquity with poor agricultural productivity, that much younger soil also exists in juxtaposition, and that certain anthropogenic processes, such as soil inversion or any other radical soil management, can rejuvenate soil for increased productivity. Younger soil occurs wherever there is an accumulating environment where relatively young materials are being deposited (e.g., alluvium), or eroding circumstances where less weathered materials become exposed such as following colluvial or deflation activity. Depositional materials are not necessarily younger when they result from redistribution of highly weathered materials such as by aeolian activity. Certain soil types may be considered as self-rejuvenating if they exhibit self-mulching and pedoturbation characteristics whereby less weathered subsoil material is brought up into the soil. Soil rejuvenation events, through a variety of processes, therefore occur naturally in Australia, as they do elsewhere. With respect to wheat production for illustrative purposes, it is argued that young or rejuvenated soil is more agriculturally productive, and that certain anthropogenic processes (such as the addition of clay or bringing subsoil clay to the surface) that rejuvenate soil can be brought about by radical soil management.

1. Introduction

Australia has the reputation of having very old and highly weathered soil (Grant, 2007; Price, 2010) in a landscape of great antiquity (Taylor, 1983; Twidale, 2007; Twidale and Campbell, 2005). Taylor (1983); Beckmann (1983) and McKenzie et al. (2004) note the widespread infertile nature of Australian soil associated with prolonged deep weathering. This poor fertility of Australian soil can partly be attributed to a lack of the kinds of rejuvenation processes that occurred in Europe and North America, such as Pleistocene glaciation (Taylor, 1983; Twidale and Campbell, 2005) which removed much of the older soil. However, Australia has also had some rejuvenation episodes such as tertiary volcanic activity particularly in the eastern part of the continent (Green, 1969; Beckmann, 1983; Twidale and Campbell, 2005) that has contributed younger soil materials by their weathering and redistribution.

Many soil-forming processes that occur within soil profiles have been identified (17 by Bockheim and Gennadiyev (2000)) and Table 1 categorizes high-level processes within and external to the profile that age and rejuvenate soil. Aging processes include those that remove elements or materials from the soil either vertically downwards or laterally. While some elements (e.g., salts) may move upwards, such a process is not necessarily aging even though it may be symptomatic of land management (clearing and irrigation) in an old weathered landscape (Isbell et al., 1983). Accretion materials such as alluvial, lacustrine, colluvial, estuarine and wind-blown deposits represent the redistribution of materials (possibly from a younger source) and rejuvenation processes. Another natural in situ rejuvenation process in swelling soil types is given by self-mulching shrink-swell clays where subsoil material may gradually be brought to the surface. Australia therefore has a range of weathered soil materials, from the ancient relatively infertile to relatively young that subsequently influences agricultural production.

Recently, the rate of soil formation by conversion from consolidated parent material has been estimated as a global average of 114.27 ± 10.93 mm kyr^{-1} or about 0.1 mm per year (Stockmann et al., 2014). This conversion rate does not indicate the rate of profile differentiation, such as the development of clay rich subsoil or leaching rates.

Given the appropriate conditions of soil formation and parent material composed of a mixture of sand and clay (as opposed to all clay or all sand), a consequence of soil aging is the tendency for the soil to become more texturally differentiated and duplex (as first defined by Northcote (1960)) over thousands of years (Walker, 1962; Chittleborough, 1992), and to exhibit many of the constraints listed above. The rate of differentiation of a duplex profile in an unconsolidated parent was estimated as greater than 10,000 years (Walker, 1962) and given as from 10^3 years to 10^6 years by Walker (1989). The aging sequence of textural differentiation is depicted in Fig. 1 with indicative dates given based on Walker (1989).

A rejuvenated soil is one where the effects of aging through geological time are reversed enabling it to provide the physical and chemical conditions desirable for optimal agricultural production. A rejuvenated soil would not exhibit the profile differentiation of a duplex soil.

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Table 1
Summary of soil aging and rejuvenation processes.

Soil aging processes	Soil rejuvenation processes
Weathering	Aerial additions
Loss of materials	Alluvial and colluvial additions
Eluviation	Geological additions such as volcanic ash
Illuviation	Geological removal of weathered material
Leaching	Self-mulching
	Pedoturbation

Fig. 2 shows a generalized schematic representation of profile texture differentiation (Uniform, Gradational and Duplex and intergrades between them) over time given the appropriate parent material composition based on a mixture of clay and sand (given as quartz to indicate its resistance to weathering), and soil rejuvenation through the possible effect of natural and anthropogenic processes. The starting point in time is given as either predominantly clay or sand or a mixed texture in a Uniform (U) texture profile. Generally, in time, the uniform high clay content soil will tend towards a Gradational (G) profile as the clay content of the subsoil increases relative to the topsoil, and the uniform sandy profile will tend towards a Gradational soil if some clay is available otherwise it will remain uniform. The mixed texture profile is the most prone to differentiation and will tend towards Duplex, as indicated in the middle row of Fig. 2.

Any process that reverses the aging process of soil differentiation can be considered to be a rejuvenation event. Fresh materials deposited more rapidly than differentiation processes represent a rejuvenation process. Erosion also represents a rejuvenation process where the less weathered part of the regolith finds its way closer to the surface and within the plant root zone, such as occurred with glacial periods. This is not to imply that the rejuvenated soil will be identical to the original soil because many pedogenic processes other than texture differentiation will have occurred over time. Rejuvenation does suggest that the more severe soil constraints listed above will not be so strongly developed or through radical management, will be mitigated.

Given that severe limitations to cropping can occur in Australian soil of different types, natural fertility and ages, the aim of this paper is to consider if the amelioration practices for agricultural production used for soil in Australia and elsewhere are capable of rejuvenating soil or if more radical management is required. It can be argued that a rejuvenated soil has the potential for prolonged sustained use depending on the buffering capacity of the soil to aging. For example, a self-mulching clay soil has considerable buffering capacity to age, whereas a sandy soil has little buffering capacity to aging processes.

Regionally, Australian soil may be severely limiting for agricultural production purposes. Australian soil has been referred to as hostile and having numerous constraints (CSIRO, 2004; Armstrong et al., 2009; State Government Victoria, 2009; Price, 2010; Dang et al., 2011). These constraints – as a result of natural aging processes and perhaps exacerbated by misuse – occur to different extents and combinations in a variety of soil materials of different ages, formation processes and composition, and include: little topsoil organic matter; hard-setting topsoil; water repelling topsoil; nutrient-poor A2 horizon; dearth of natural nutrients; acidic topsoil; poor structure for water movement and root growth; toxic concentrations of elements; lack of trace elements; marked or abrupt texture contrast between the topsoil and subsoil; saline subsoil; sodic subsoil; highly acidic subsoil; highly alkaline subsoil; dense and poorly permeable subsoil; and high subsoil strength.

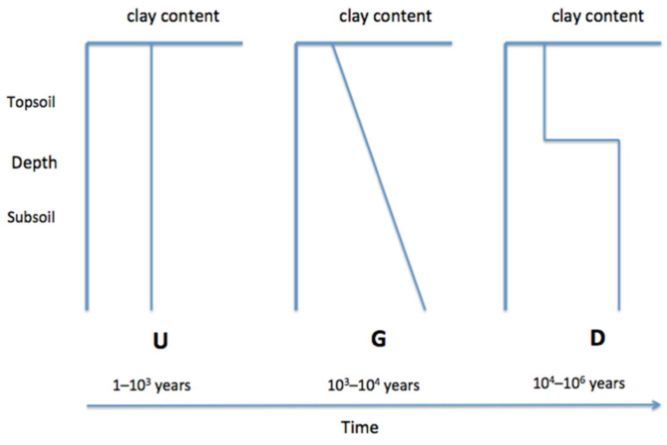

Fig. 1. Texture differentiation with time from Uniform (U) to Gradational (G) to Duplex (D) with indicative timeframes based on Walker (1989).

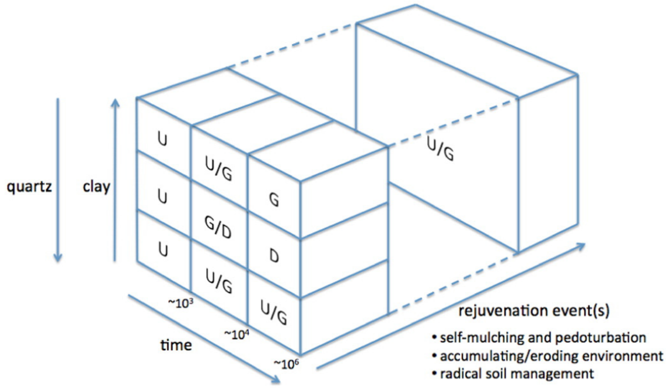

Fig. 2. Schematic representation of soil profile textural differentiation in time, starting from high clay or high sand or a mixed texture, and the reversing effects through rejuvenation events. Indicative times are based on Walker (1989).

When coupled with a climate that is often hot and dry with frequent periods of drought, these soil conditions can markedly constrain crop yields.

To examine the effects of anthropogenic rejuvenation processes, the scope of the paper is restricted to cereal crops, particularly wheat which is a major Australian crop (Fischer et al., 2014).

2. Soil types and wheat yields in Australia

Probably because of soil antiquity, on a ton per hectare basis, Australian cereal production (for a wide range of cereals) is below most developed and developing countries (World Bank, 2014). Australian wheat production is one of the lowest in the world, e.g., wheat production in Australia was 1.6 t/ha in 2009–12 (PWC, 2011), in comparison with 2.6 t/ha in 2014 in the US (USDA, 2014a), 6 t/ha as an average in Europe (Spink, 2007; Gianessi and Williams, 2011) and 3.2 t/ha in 2014 on a world scale (USDA, 2014b).

The Australian wheat belt (Fig. 3) covers a range of soil types. Expressed in terms of the recent Australian Soil Classification System (Isbell, 2002), the main soil types associated with the wheat belt are: Chromosols, Kandosols, Sodosols, and Vertosols, with significant areas of Ferrosols, Kurosols, Podosols, and Dermosols (Dalal and Chan, 2001). These soil types include the texture profiles (U, G, D) of Northcote (1960), with many of them being Duplex or approaching that differentiated state, or highly quartz rich with consequential little texture differentiation even though considerable leaching and aging have occurred.

The range of features of those soil types includes those listed above and referred to as hostile with limiting constraints. Many have a profile with a marked texture contrast between the topsoil and subsoil (Duplex) which have been referred to as the mainstay of wheat production in southern Australia (Stace et al., 1972), and others may be sandy or more uniformly clayey.

Water is a major factor in wheat yields (French and Schultz, 1984a, 1984b). These authors note that the efficiency of water use by a crop following soil evaporation losses of 110 mm is adversely influenced by