Soil constraints to crop production: an overview

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Abstract
Soil constraints limit crop production in many parts of Australia and are responsible for significant yield losses each year. Constraints can be defined as any soil characteristic that limits crop growth and thus negatively impact agricultural production. These can be physical (e.g. surface seals, compaction, waterlogging), chemical (e.g. acidity, salinity, nutrient deficiencies), or biological (e.g. soil borne diseases, declines in soil biological diversity). Soil constraints may occur singly or in combination and tend to vary both spatially across the landscape and within soil profiles, occurring in both topsoil and subsoil layers. This variability increases management complexity and improvements in our ability to identify what constraints occur and where in the soil profile they occur to effectively target management. Constraint management approaches can generally be grouped into three broad categories: a) amelioration, which focuses on the removal of constraints or reduction in their severity; b) agronomic management, which uses techniques to maintain crop production despite the presence of soil constraints; and c) land use change, which is used when amelioration or agronomic management are not logistically or economically feasible. This paper provides a brief overview of the different types of constraints affecting Australian cropping systems, the impact of these on crop production, and management options available to improve farm productivity and profitability.

Keywords
acidity, alkalinity, salinity, sodicity, compaction nutrients.

Introduction

Soil constraints reduce agricultural productivity over much of Australia and can be defined as any soil characteristic that restricts plant growth and lowers crop production. Constraints can be naturally occurring or induced by inappropriate agricultural management and can either be physical (e.g. surface seals, compaction, waterlogging, and erosion), chemical (e.g. salinity, sodicity, acidity, alkalinity, nutrient deficiencies, and the presence of toxic elements, and/or biological (e.g. soil-borne diseases, declines in soil biological diversity).

Soil constraints can reduce crop growth a) by reducing the movement of water and air into and within the soil profile e.g. due to the development of surface seals or compacted layers that reduce hydraulic conductivity; or b) by restricting a plant's ability to grow and function, e.g. due to the presence of physically or chemically hostile layers that prevent root growth and/or water and nutrient uptake (Dang et al., 2006). This can have a major impact at a farm level by decreasing agricultural output, increasing management costs, and thus decreasing farm income (Orton et al., 2018). It can also impact society at a broader level by decreasing country wide productivity and food security. Many negative environmental problems can also arise from soil constraints, including increased runoff and erosion, and thus pollution of surrounding waterways, and increased production of greenhouse gases/ decreased soil carbon storage (Figure 1).

This paper provides a brief outline of the impact of soil constraints on crop production in Australia, and the importance of accurate constraint diagnosis. It then discusses broad management principles and considerations that can be used to develop effective management options.

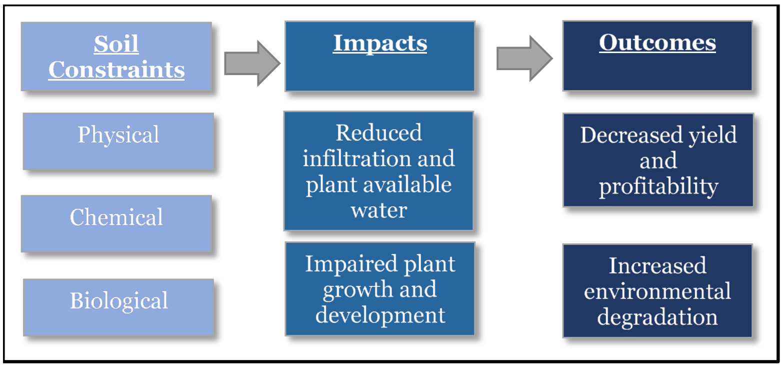

Figure 1 Summary of the major types of soil constraints, their impacts, and subsequent outcomes

Impact of constraints

Soil constraints have a major impact on farm productivity and profitability Australia wide. For example, it has been estimated that just three constraints - sodicity, salinity, and acidity - are responsible for annual losses in production of nearly $AU 1900 million dollars in the wheat crop alone (Orton et al., 2018). Constraints may occur singly or in combination and tend to vary not only spatially across the landscape but also within soil profiles, occurring in both topsoil and subsoil layers. This increases management complexity and highlights the importance of understanding exactly what constraint/s occur where in the soil profile in order to effectively target management and increase production. On a national level, this allows management agencies to effectively identify those constraints having the most impact on a region's agricultural production and prioritise resources appropriately. At the farm and paddock scale, it allows us to identify appropriate management on a site-specific basis. This allows for better resource use to both improve production and the sustainability of the food supply, and maintain environmental quality (Gebbers & Adamchuk, 2010).

How to identify the location of soil constraints at both a national and farm level is an active area of research. Traditionally, soil surveying and mapping has been used as the primary means of identification. However, this tends to be both time consuming and prohibitively expensive. Newer techniques that focus on identifying consistently low yielding areas (i.e. season after season) across a region, property, or within a paddock/field to identify the presence of a constraint are proving more promising (Dang et al., 2011; Orton et al., 2018). At a farm level, lower yielding areas can be located approximately via farmer observation, or more precisely using GPS technology attached to harvesting equipment to map yield across the paddock. Remote sensing technology that monitors indicators of plant growth (e.g. Normalised Difference Vegetation Index -NDVI- taken via satellite imagery) have also been used successfully to identify yield decline at both a regional and farm scale (Dang et al., 2011; Orton et al., 2018). Once lower yielding locations have been identified, the source/s of the constraint can then be identified using standard soil analysis that identify chemical, physical, and/or biological soil characteristics capable of limiting yield

Management of soil constraints

Once it is understood what constraints occur, and where these are located, knowledge of the most effective techniques to manage crop production is required. Soil constraints rarely occur in isolation and interact in a site-specific way to create growing environments that vary from location to location. Consequently, it is not possible to use a 'one size fits all' approach to management, and different combinations of techniques will be appropriate in different situations. However, the management options available can generally be grouped into three broad categories: amelioration, agronomic management, and land use change (Figure 2).

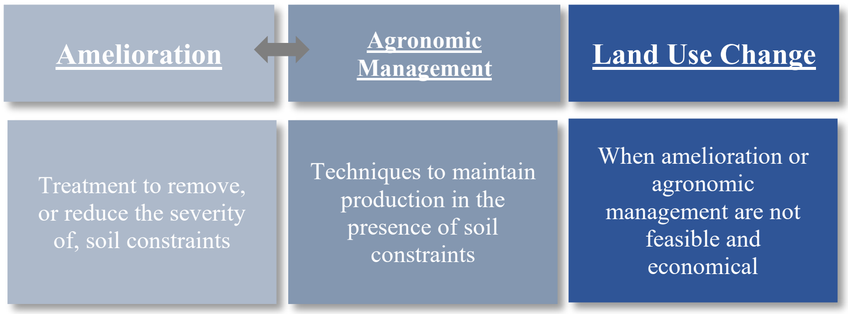

Figure 2 Illustration of the three broad approaches available for the management of soil constraints.

Amelioration

Amelioration involves the use of some management input to correct or improve a constraint. Common examples include the application of lime to treat soil acidification, gypsum to treat soil sodicity, fertiliser to treat nutrient deficiencies, and cultivation to treat compaction. Because soil amelioration has been used extensively for many years, a broad knowledge base exists regarding how it can be best applied. However, significant gaps in our understanding still exist, particularly regarding the most appropriate and efficient use of ameliorants where multiple constraints exist and how best to use amelioration when constraints occur in subsoil environments.

Where a soil is affected by multiple constraints, these must all be ameliorated before maximum yield can be achieved. In these situations, a combination of amendments can sometimes be more effective than singular applications (Harris & Rengasamy, 2004; Nan et al., 2016; Stamford et al., 2007; Tahmasbian et al., 2019; Tang et al., 2006; Valzano et al., 2001). This typically occurs when different amendments improve different aspects of problem soil behaviour, and/or when one amendment increases the effectiveness of another. However, combinations of ameliorants do not always lead to greater yield increases, and improved understanding of when and why combinations of amendments will be effective is required for a range of environments and constraints.

When constraints exist in the subsoil, treatment with ameliorants can also be challenging. For ameliorants to successfully treat subsoil environments, they must either be placed at high enough rates on the surface so that they will leach down the profile (which can often take a long time, particularly in rainfed systems), or be physically placed at depth (which is logistically challenging and expensive). Our options for the treatment of constraints occurring in subsoil environments are currently limited and greater research is required. Advances in this area will be particularly beneficial for rainfed agriculture in drier climatic regions where crop production is often reliant on moisture stored in the subsoil.

Agronomic management

Agronomic management refers to the manipulation of farming practices to help crops grow better despite the presence of a soil constraint. This can be used either in conjunction with amelioration, or as an alternative option where amelioration is uneconomic or likely to take an extended time. However, while agronomic management has the potential to help improve production on constrained soils, there is often less emphasis on this approach compared to amelioration and improvement in our understanding of its potential is required. Examples of agronomic management can include:

- Accurate identification of constrained areas so that these can either be excluded from production, where there is a high risk of negative returns, or managed differently (e.g. variable fertiliser rates);
- The identification and use of plant species/cultivars that are best suited to growth in a particular soil given its constraint characteristics; and
- The manipulation of cultural practices such as sowing times, row spacings, seeding densities and tillage management to best manage constraints.
- Application of yield limiting nutrients

Land use change

In some instances, soil constraints may be so severe or difficult to manage that sustaining crop production using either amelioration or agronomic management is not logistically or economically feasible. Under these circumstances a move to an alternative land use may be the most appropriate management option.

Conclusions

The successful identification and management of soil constraints is clearly required to maximise agricultural productivity. However, the complexity of this task is great, and sophisticated and coordinated management responses are required. We are currently editing a book that will provide a comprehensive overview of the types of physical, chemical, and biological constraints that impact crop production worldwide. The extent of these constraints, their effect on crop production, and the most promising approaches to manage their impact will be discussed. In addition, comprehensive case studies of important cropping regions worldwide will be presented to outline the unique management challenges, and current state of the art in soil constraint management, in different geographical and climatic regions. This book will provide a comprehensive summary of our knowledge of soil constraints to crop production and highlight the most important advances in soil constraint management.

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