Soil quality benefits of break crops and/or crop rotations-a review

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Abstract
Cropping systems in Western Australia (WA) are strongly dominated by cereals (wheat, barley and oat
hay) and are intrinsically linked to soil quality and moisture supply. So a major research challenge is to
devising cropping systems that improve soil health and maximise water-use efficiency. For a profitable and
sustainable production system there is a clear need for ‘break crop’ to provide a pest, disease and weed
break, conserve soil moisture; adding soil organic matter and nutrients and to help alleviate soil physical and
structural problems. This review article demonstrates the role of ‘break crops’ and/or of ‘crop rotations’ in
providing potential soil quality benefits for profitable and sustainable crop production systems.

Key Words
Break crops, crop rotation, soil quality.

Introduction

Most soils in WA were extremely deficient in N, and not capable of supporting profitable yields of wheat
until the introduction of legumes into the rotation. The introduction of grain legume crops or legume-rich
pastures provided N to a subsequent cereal or oilseed crops (Rowland et al. 1988, 1994). The use of lupins as
a major rotation crop for sandplain soils coincided with the availability of herbicide options and reduced
tillage. Lupins provided farmers with a profitable alternative to pasture legumes and gave them an option to
control grass weeds using herbicides in the non-cereal phase of the rotation. An unknown part of the
observed yield increase of wheat following pasture legumes was probably also due to a reduction in root
diseases. More recently, the widespread use of canola in many rotations has added an extra management tool
to maintain profits and for controlling grass weeds. However, the yield increases in the following wheat crop
that were observed in eastern Australia (Angus et al. 1991) have been less evident in the west, possibly due
to poorer soil fertility. The reason there is so much interest in crop rotations in WA (or elsewhere) at the
moment is because there is a sense of belief that this will move the current farming system towards a more
‘sustainable’ farming system. With the monoculture (of wheat/barley/oat hay) and the predictability of the
current system, any variation in the cropping rotation would be of benefit.

Choice of break crops to grow in addition to cereals and the fertility building phase are crucial to both the
agronomic and economic success of the rotations. There are four specific functions that a break crop may
perform, namely - improvement in soil health; conservation of soil moisture; weed control and pest and/or
disease control. Individual break crops may perform one or several of these functions. A good break crop is
also expected to produce satisfactory yields, be of marketable quality, and produce an economic return for
the farmer. The main principles of crop rotation design are described in Table 1.

The appropriate choice of crops within the rotation and their sequence are crucial if nutrient cycling within
the farm system is to be optimised and losses minimised over the short and long term. Each crop species has
slightly different characteristics, e.g., N demanding or N2 fixing, shallow or deep rooting, amount and quality
of crop residue returned. These characteristics along with existing biotic and abiotic factors determine the
ultimate suitability of a break crop in a given cropping system.

This review highlights the fact that much information currently existing in the scientific literature on role of
break crops or crop rotations could be utilised to optimise certain management practices for profitable and
sustainable crop production. The topics discussed in this review on soil quality are in the order of their
importance to the West Australian cropping systems.

Soil nitrogen

One of the persistent nutrient management questions associated with the legume rotation is whether the N
contribution from legume fixation is responsible for much, if not all, of the beneficial rotation effect. Many
studies have shown that cereals derive both yield and N benefits from rotations with grain legumes compared
with cereal monoculture (Kirkegaard et al. 2008). The yield advantage may be entirely due to N or to other
factors, but more commonly a combination of both (Chalk 1998). Evans et al. (2001) estimated that average net N input from grain legumes to be 47 kg/ha N in south eastern Australia and 90 kg N/ha in south western Australia. Removal of the above ground pea residues, which contained less than 1% N, had no effect on residual N value. Stevenson and van Kessel (1996) found that 91% of the wheat yield benefit from a preceding pea crop came from reduced leaf disease and weed infestation, while only 9% was estimated to have derived directly from N. Benefits in N nutrition to wheat may also arise from break crops simply because the healthier root system is able to utilise existing soil N or applied N more efficiently (Cook 1990). Non-legume break crops may also differ significantly in the amounts of mineral N left in the profile. Kirkegaard et al. (1997) found that residual N remaining after a range of winter oilseeds was a key factor in determining subsequent wheat yields in the absence of disease. Linseed had a shallower rooting system, produced less biomass and left 30-50 kg/ha more N in the profile at harvest than canola or mustard. Accumulation of mineral N from break crop residues may also differ during the fallow period prior to cropping and this may not be simply related to C: N ratio of the residues (Kirkegaard et al. 1999).

Table 1. Rationale of crop rotation in farming systems.

<table>
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<tr>
<th>Principle</th>
<th>Reasoning</th>
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<tr>
<td>Rotate deep and shallow rooting crops</td>
<td>Improve soil structure, aeration, water-holding capacity, and drainage</td>
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<td>Alternate crops with large and small root biomass</td>
<td>High biomass crops increase the organic matter remaining in the soil for soil microbial and macrofaunal populations</td>
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<tr>
<td>Rotate N₂-fixing and N-demanding crops</td>
<td>Attempt to meet farm’s N demands from within the system</td>
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<td>Alternate weed-susceptible and weed suppressing crops; rotating varieties of same crop e.g. EGA Eagle Rock wheat vs Clearfield wheat, Mandelup lupin vs Jenabilup lupin, TT canola vs IT canola or conventional canola</td>
<td>Interrupt weed life cycle to reduce populations; decreasing likelihood of developing herbicide resistance in weeds by using different herbicides for respective variety and their varied mode of action</td>
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<tr>
<td>Grow crops with different pest and disease susceptibilities</td>
<td>Break pest and disease life cycles, reduce host plant presence in rotation</td>
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<tr>
<td>Grow catch crops, green manures, and undersow crops</td>
<td>Maintain soil cover to protect for erosion and leaching</td>
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<tr>
<td>Balance forage and cash crops</td>
<td>To make rotation economically as well as ecologically viable</td>
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<tr>
<td>Fallow</td>
<td>Soil water storage, weed control</td>
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Soil organic matter

Soil organic matter (SOM) is a key indicator of quality as it influences biological activity, serves as a nutrient reservoir, and impacts soil aggregation. Heenan et al. (2004) from a long term rotational study in Wagga Wagga NSW reported that stubble retention in legume-wheat rotation maintained higher levels of SOC than stubble burning. The effects of management treatment on soil total N were similar to effects on SOC. Where change in SOC and TN occurred, there was no evidence that equilibrium had been reached, although a change in slope had occurred in many treatments. Masri and Ryan (2006) from Cropping System Productivity trial at ICARDA Syria reported that some rotations, e.g., medic (Medicago sativa) and vetch (Vicia faba), significantly increased soil organic matter (12.5–13.8 g/kg versus 10.9–11 g/kg for continuous wheat and wheat/fallow).

Phosphorus

Phosphorus (P) is a major limiting nutrient for crop production on many Australian soils due to high P fixation and low levels of plant-available soil P. Only 10-20% of the applied P is utilised by crops in the year of application and subsequent usage of the residual P rarely exceeds 50% (Bolland and Gilkes 1998). Fertiliser P reacts with soil constituents and is readily ‘fixed’ as adsorbed P, sparingly soluble P-precipitates (Al-P, Fe-P or Ca-P) or converted to organic forms that are largely unavailable to most crop plants. Thus a major challenge is to find ways to improve the P use-efficiency of high P fixing soils. One approach that has potential benefits on P availability is the incorporation of P-mobilising species into the cropping system (Horst et al. 2001). Several legume crops can mobilise soil and fertiliser P through the exudation of organic-acid anions such as citrate and malate and other compounds from their roots from their roots eg, chickpea (Veneklaas et al. 2003), and white lupin (Keerthisinghe et al. 1998). This mechanism enables some of these species to acquire P from soil sources that are not readily available to non-secreting crops. A number of studies have reported improved growth and P nutrition of less P-efficient crops following organic-union exuding legumes (Hocking and Randall 2001). Despite being a promising approach to improve the P-use.
efficiency of cropping systems, however little is known about the conditions (soil type, plant species) and mechanisms governing these benefits.

Soil structure and physical properties
In WA soil physical and structural problems have become widespread particularly in certain soil types such as earthy sands and sandy duplex subsoils. Some break crops can be used to help alleviate such problems, either because of the nature of the break crop itself or as a result of cultivation methods used during production. The roots and residues of break crops may influence several aspects of soil structure through exudation or release of stabilising or destabilising substances in the rhizosphere, root and associated hyphal enmeshment or fragmentation, and the production of stable biopores. Reeves et al. (1984) in a south Australian study reported that differences in soil water-stable aggregates and bulk densities following wheat and lupin crops were small and inconsistent. Chan and Heenan (1996) reported soil following canola and lupin was more porous, had lower soil strength and had stronger, more stable aggregates than soil after peas or barley, and the improvements related to the impacts of roots on soil aggregate formation and macro-pore creation. Interestingly, both lupin and canola are non-AMF (arbuscular mycorrhizal fungi) hosts so that the improvements in aggregate stability following those species could not be explained by glomalin production by the associated AMF as has been recently demonstrated for other crops by Wright and Andersen (2000). Cresswell and Kirkegaard (1995) reviewed the evidence for improvements in subsoil structure by break crops and concluded that the effects were either small, not evident, or could not be adequately distinguished from additional influences of break crops such as reduction in soil-borne diseases.

Conclusion
Benefits of break crops in rotation for crop productivity have been identified, but processes and mechanisms responsible for those benefits need to be better understood particularly under WA growing environments. There is serious lack of published on data under WA growing conditions. Most of the work reported in this review has been done elsewhere. Long-term trials are needed if reliable conclusions are to be reached on the performance of break crops in different WA climatic zones and soil types. This is a critical area for basic and applied research. No one ‘crop rotation’ will be the ‘right’ rotation, as the goals trying to be reached may vary and hence one situation may require one rotation and this may be completely unsuitable in another situation.

Dynamic Crop Sequence (DCS) trial in Katanning and Wongan Hills in WA started recently is the first step in the right direction to understand the role of break crops in WA cropping systems. A dynamic cropping system represents a long-term strategy of annual crop sequencing that optimises crop and soil use options to attain production, economic, and resource conservation goals by using sound ecological management principles. These trials look at quantifying the effects of crop residues on the following crop in the sequence with respect to water use, disease flow, stability of yield, economics and measures of soil health from a total of 100 treatment combinations generated from wheat (with and without Jockey fungicide seed treatment), barley, oats (grain and hay), field pea, lupin, canola, green manure and fallow. This is holistic approach in management of soil moisture, weeds, diseases and nutrients through use of break crops in rotation and suitable agronomic practices. The end objective of trials is to generate information about which crop is best to sow in what situation and how to combine crop sequences to maximise opportunities. This agronomic research will also be backed by an economic analysis to give farmers more confidence in the decisions they make about their cropping program in WA or elsewhere with similar growing conditions.

References


