Potential impacts of subsoil constraints on canola productivity in southern NSW

Tony Swan[1], John Kirkegaard[1], John Angus[1], Mark Peoples[1], Mark Conyers[2], Albert Oates[2], Graeme Poile[2], and Sergio Moroni[2]
[1]CSIRO Sustainable Agriculture Flagship, CSIRO Plant Industry, GPO Box 1600 Canberra, ACT 2601, Australia
[2]EH Graham Centre for Agricultural Innovation (alliance between NSW DPI and Charles Sturt University), Wagga Wagga Agricultural Institute, PMB, Wagga Wagga, NSW 2650, Australia
Email: tony.swan@csiro.au

ABSTRACT

Research investigating declining canola yields in southern NSW identified subsoil constraints as a potential contributing factor. We investigated the impact of subsurface compaction (hardpans), acidity, and/or subsoil sodicity or salinity on canola yields in replicated on-farm experiments undertaken between 2007 and 2009. Treatments included combinations of surface and/or deep applied lime or gypsum, with or without deep-ripping to 25-30cm. After 3 years of experimentation at 7 locations between Greenethorpe north of Young and Corowa near the Victorian border that differed in underlying subsoil constraints, we concluded that canola was surprisingly tolerant to most subsoil constraints. Specifically: (a) Canola would not be expected to respond to deep-ripping to remove subsurface compaction where compaction was determined by measures of penetrometer resistance to be < 3 MPa at field capacity. Above 3 MPa crop responses may be possible; however, the economic viability of deep-ripping will depend upon seasonal conditions and whether a residual value persists over several years; (b) Canola appeared to be relatively tolerant of subsurface acidity where the surface soil was limed, except where exchangeable aluminium exceeded 20%, concentrations of manganese were toxic, or where the acid 'throttle' was thicker than 20cm deep; (c) Canola would not be expected to respond to deep placement of gypsum to ameliorate subsoil sodicity unless subsoil exchangeable sodium levels were >15% and the growing season rainfall exceeded 400mm; (d) Canola rooting depth and yield were sensitive to subsoil salinity, but effects were masked in a favourable season. Electro-magnetic (EM) surveys combined with diagnostic soil sampling can identify saline zones where canola should not be grown.

Key words: Compaction, acidity, sodicity, salinity, grain yield

INTRODUCTION

A compilation and analysis of paddock-based survey data (CanolaCheck) collected from around 150 commercial canola crops per year from 1991 to 2001 estimated that an average 9% decline in grain yield of dryland canola had occurred across the medium- and high-rainfall areas of southern and central NSW over that 10 year period (Mead et al 2004). A similar trend was also evident in the more extensive census and survey data collected by the Australian Bureau of Statistics (ABS), and further analysis of the ABS data suggested that the trend could not be simply attributed to poor seasonal conditions (Kirkegaard et al 2006). Disease was considered to be a likely cause for the observed yield decline in canola in the better rainfall years and the higher rainfall areas (Kirkegaard et al 2006). However, restrictions to taproot growth as a result subsoil constraints, and late season water stress were also implicated as possible contributing factors to canola's under-performance in three regions in southern NSW from data collected from 132 farmer's crops over three cropping years (Lisson et al 2007). More recently similar observations have been reported in Europe where poor yields of Brassica crops were found to be related to restrictions to root penetration (Peltonen-Sainio et al 2011).

This paper reports the main outcomes from a series of on-farm experiments undertaken in southern NSW as part of the GRDC-funded "Canola Yield Decline" project (CSU00008) between 2007 and 2009. The project was co-ordinated by the E H Graham Centre in partnership with the NSW Department of Primary Industries, CSIRO, and the local grower group FarmLink. The project specifically aimed to examine the effects of high soil strength, subsoil sodicity, salinity and acidity on canola productivity.

MATERIALS AND METHODS

At the commencement of the project, farmers' paddocks in areas of southern NSW which either had been identified as experiencing under-performing canola crops by previous studies (e.g. Lisson et al 2007), or local agribusiness consultants were examined as potential sites for experimentation. All paddocks were EM surveyed (EM38) to identify paddocks with underlying salinity problems, and measured for soil strength to 40cm using a Rimic cone penetrometer. Paddocks were then soil sampled at multiple locations to 1.5m depth and analysed for pH (1:5 in $CaCl_2$), exchangeable sodium % (ESP), and electrical conductivity (EC_e measured in saturated paste extract) at intervals down the profile. Sites were subsequently selected for experiments on the basis of whether the subsurface (the A horizon, either below plough layer or below 10cm depth) exhibited a compacted layer (penetrometer resistance > 2 MPa at field capacity) and/or was acidic (pH_{Ca} <5.0), and/or the subsoil (B horizon, usually below 20cm depth) was sodic (ESP >15%), or saline (EC_e > 2 ds/m).

Information presented here are derived from on-farm studies undertaken between 2007-2009 on three acid/compacted sites (Greenethorpe, Milvale and Culcairn), three sodic/compacted sites (Lockhart, Rand and Corowa), and a site with a variable saline subsoil (Yuluma). Experimental treatments were generally a combination of three or four replicates of surface and/or deep applied lime or gypsum. Wherever possible, common treatments were imposed to allow comparisons between sites. These included: (a) control (nil treatment), (b) deep-rip to 25-30cm, and (c) deep rip + injected lime or gypsum. Deep ripping and injection was carried out at 45cm tyne spacings using a Yeomans deep ripper modified with a trailing cart, from which lime or gypsum was blown down tubes located behind the ripper tynes. Lime was injected at the acid sites at rates of either 4.0 t/ha (Greenethorpe), 3.75 and 7.5 t/ha (Milvale), or 7.5 t/ha (Cucairn). Gypsum was applied at the sodic sites at rates of either 4.0 t/ha (Lockhart), 3.5 t/ha (Rand), or 2.2 t/ha (Corowa). In the case of salinity, canola's performance was compared at different locations within the paddock at Yuluma which EM survey data and EC determinations had indicated differed in levels of salinity.

The trials represented a mixture of commercial size replicated strips that were sown using farmer equipment, and smaller scale 'white-peg' studies. Plant growth was quantified 8-10 weeks after sowing and towards the end of flowering by hand-harvesting 1m^2 quadrat areas from each treatment replicate. Canola root architecture was examined at maturity by excavating the root systems of 25-50 plants per plot and visually rating the extent of root distortion as described by Lisson et al (2007). Rooting depth of the canola growing at each sampling locations was quantified by soil coring using the 'core-break' method whereby the soil core was broken at 10cm intervals and each section examined for evidence of roots. The cores were retained and analysed to provide profile measures of pH, ESP and EC directly experienced by the harvested plants. Grain yields were measured using both hand- and machine-harvests at maturity. Additional yield data were also collected from yield monitors where these were already fitted in farmer's harvesters.

RESULTS AND DISCUSSION

The main finding of experiments undertaken to examine the impacts of soil constraints on canola growth and yield was a negative rooting depth response to salinity in 2008 and 2009, although reductions in dry matter and yield in the presence of salinity were observed in the drier season of 2008. The effects of compaction, acidity and sodicity were less pronounced than salinity (Table 1). Each of these potential soil constraints will be examined in more detail individually in the following sections.

Subsurface compaction

A canola paddock survey conducted across soil types in southern NSW in 2004/05 indicated that 37 out of 39 paddocks had compacted subsurface layers (soil strength 2MPa or greater), with >60% of the canola crops examined south of Wagga Wagga exhibiting severe root distortion (Lisson et al 2007). A European investigation also reported that under some conditions yield loss of Brassica crops can be linearly related to reductions in the depth of root penetration as a result of soil compaction (Peltonen-Sainio et al 2011). These data suggested that canola could be sensitive to compaction and restricted tap-root growth can translate into lowered crop yield.

Table 1. Summary of canola's response to amelioration treatments applied in farmer's paddocks at different locations in southern NSW with potential constraints to root growth imposed by compaction, acidity or sodicity.

Constraints & locations	Treatment & canola response	
Acidic & compacted	Lime injection	Deep-ripping
Greenethorpe (x2)[1]	nil	Dry matter only in '07
Milvale	nil	nil
Culcairn	nil	nil
[Culcairn –barley]	[Dry matter response in '08]	[Dry matter response in '08]
Sodic & compacted	Gypsum injection	Deep-ripping
Lockhart	nil	nil
Rand	nil	Negative yield response '08
Corowa	nil	nil

[1] Trials were undertaken on 2 different farms at Greenethorpe.

Deep-ripping treatments were applied to seven trial sites with a compacted subsurface in the current study. Yet despite substantially reducing soil strength to a depth of 30cm and significantly decreasing the severity of canola root distortions at all sites, deep-ripping resulted in increased canola dry matter production at only the two Greenethorpe sites in 2007 (Table 1). Increased early dry matter was correlated with a higher proportion of roots deeper than 10cm at one Greenethorpe site (data not shown), but unfortunately, the early beneficial effect disappeared when crops ran out of soil water. At the second site, increased shoot dry matter was still evident at flowering in the deep-ripped treatment (6.24 t/ha cf 4.36 t/ha in the control); however, a positive grain yield response was not subsequently recorded due to a severe frost late in the season. No dry matter or grain yield responses were recorded at any other trial location except Rand, where yield reductions were observed in 2008 (Table 1). This was believed to have resulted from a substantial loss of surface and subsoil water reserves in the process of ripping which was not replaced during the lower than average rainfall growing season. In this case the lower yield at Rand reflected reduced access of canola roots to plant-available soil water.

The inconsistent results reported here are comparable to many of the deep-ripping outcomes described in a recent review which collated the results of trials conducted in south-eastern Australia between 1980 and 2007 (Kirkegaard et al 2008). The review found only limited evidence of economic responses to deep-ripping with yield increases being observed in only 5 of the 24 trials examined. In a number of instances no yield responses were observed even where increases in early vegetative biomass had been recorded.

Although yields in our study were compromised by a series of dry growing seasons, our observations, combined with the review findings, have led us to conclude that the commonly accepted soil strength threshold of 2MPa at which root growth is believed to be restricted may not apply to relatively permeable non-sodic soils in south-eastern Australia where cracks and pores in the soil enable root penetration through compacted layers. We now propose that 3Mpa at field capacity may be a more appropriate threshold for canola.

Subsurface acidity

On the red and red-brown earths of southern NSW with low buffering capacities, farming practices have resulted in surface pH levels ranging from around pH_{Ca} of 6.0 to < 4.5 in the absence of lime. As soil pH decreases the concentration of toxic forms of aluminium and manganese increase. Canola is widely considered to be sensitive to acid soils and is particularly sensitive to manganese (Mn^{2+}). Whilst surface liming has become an accepted practice for canola cropping, questions have arisen concerning the impact of the development of subsurface acidity on canola's growth since even though surface soil is limed, an acid 'throttle' remains between the limed surface and the naturally neutral or alkaline subsoils.

Lime injection treatments were applied to four trial sites which had a limed surface above an acid throttle between 5 and 30cm depth. The lime injection was found to be effective at increasing the pH of the original acid throttle. For example, pH profiles at the Culcairn site showed lime injection increased the most acidic depth (10-20cm) from pH_{Ca} of 4.1 to 5.0. Yet despite this, no canola responses were recorded at any of the sites over the three years of the project, although the acid-sensitive species barley sown at the Culcairn site in 2009 did show a significant response (Table 1). Manganese was not present at sufficiently high levels to restrict root growth at any of the experimental sites, and the canola roots in the control treatments appeared capable of pushing through the acid throttle into the neutral subsoil deeper in the profile without damage.

The results from our field study, in conjunction with subsequent glass-house trials not reported here, suggest that provided the surface soil is not acid, exchangeable aluminium is <20%, concentrations of manganese are not toxic, and where the acid 'throttle' is <20cm, then canola appears to be relatively tolerant of subsurface acidity. Whilst these results are reassuring for canola production acid throttles remain of concern for natural resource management. Profit from the canola-wheat system has paid for liming in mixed farming areas for the past 10-15 years and allowed the re-introduction of acid-sensitive species like lucerne. We don't know whether other species are as tolerant to acid throttles as canola, and continued development of acid throttles may close off options for future crops and pastures.

Subsoil sodicity

Soils are generally considered to be sodic if the ESP is >6% in the topsoil or >15% in the subsoil. Sodic soils tend to disperse when wet and result in a hard, dense structure when dry. Applying gypsum can improve the structure of sodic soils by preventing the soils from dispersing.

Injected gypsum treatments were applied to three trial sites with sodic subsoils, but no crop responses to gypsum were recorded (Table 1). This was believed to be largely due to below-average rainfall being experienced over the duration of the project. Deep placement of gypsum would be expected to be most beneficial for canola in exceptionally wet years (e.g. when growing season rainfall >400mm) by preventing or delaying the onset of waterlogging conditions in sodic clay soils (e.g. Chan et al 2006).

Subsoil salinity

A soil is generally considered saline if EC_e is >2 dS/m. Apart from the direct toxic effects of some salts such as sodium and chloride on the plant, subsoil salinity can decrease plant growth and yield by reducing the capacity of plant roots to extract water from soil as a result of the osmotic effects of the salts.

A site at Yuluma in southern NSW was selected for its variable subsoil salinity content based on EM readings of apparent EC (EC_a) ranging from 0.91 to 2.75 dS/m. Variable salinity levels across the paddocks were correlated to canola rooting depth, shoot dry matter production and yield over the 2008 and 2009 growing seasons. Although previous research had demonstrated that canola is relatively salt tolerant compared to wheat and legumes, the current study found that rooting depth declined as salinity increased in both years (Fig. 1a).

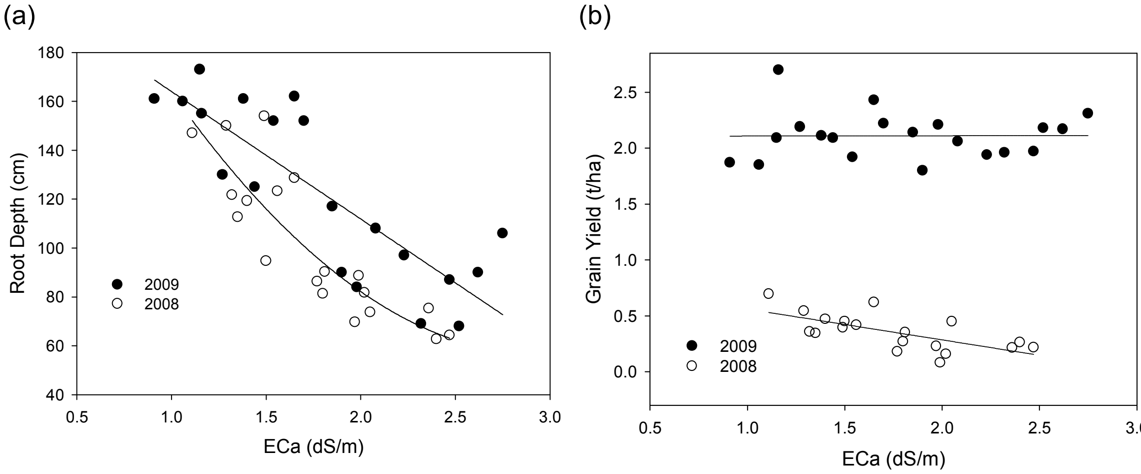

Fig. 1. The influence of salinity (apparent electrical conductivity from EM survey data) on (a) the maximum rooting depth of canola, and (b) canola grain yield at Yuluma in 2008 and 2009.

However, this only translated into a dry matter (data not shown) and yield penalty in 2008 when conditions were dry (93mm in-crop rainfall; Fig. 1b). The higher rainfall in the 2009 growing season (185mm in-crop) effectively masked the effects of the saline subsoil (Fig. 1b). In other words the restricted rooting depth at higher levels of subsoil salinity depicted in Fig. 1a had little impact on subsequent grain yield in a favourable season where there was sufficient rainfall and surface moisture post-flowering that the shallower roots were able to extract enough soil water to adequately support canola growth and development.

Where subsoil salinity is suspected, EM surveys combined with ground-truthing should be used to identify paddocks where canola may not be suitable. A more salt-tolerant species such as barley may be a more appropriate crop choice in such circumstances.

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