Cereal yields associated with changes in soil characteristics following six years of acacia

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ABSTRACT

A field study was undertaken in 1999 at Rutherglen to evaluate the performance of oats (*Avena sativum* L.) in relation to changes in soil characteristics following six years of acacia (*Acacia spp*) or continuous annual crops. Compared with the continuous cropping belts, the acacia belts had 23 % more mineral nitrogen (N) and 28 % more organic matter in its soil, but produced 38 % less oat yield due mainly to the drier soil profile and partly to a greater weed infestation. Further analyses with simulated wheat (*Triticum aestivum* L) showed that in years with average or below average rainfall, grain yield in the first cropping season after acacia could be reduced by up to 74 %. However, the water deficit existing after acacia can be overcome within two years especially during a succession of wet seasons, while high soil N in the acacia belts continued to improve yields for up to five years. No drainage was simulated under wheat grown after acacia, but wheat in the continuous cropping could lose up to 24 % of the annual rainfall through this process.

Key words

Subsoil constraint, ‘primer plants’, oats, wheat, soil water, soil nitrogen.

Introduction

In the high rainfall cropping zones, waterlogging due to low permeability of the subsoil, and deep drainage constitute major constraints to crop productivity and pose major environmental hazards in terms of nutrient leaching and rising ground water. On these soils, practices such as application of gypsum, lime and manure have limited ameliorative benefits due to the depth of the problematic layer (5). On such soils, a more effective approach with longer-term benefits is to improve soil structure using plant species with deep roots capable of punching through the compacted layers (3). These plants grown primarily for their soil ameliorative ability are termed ‘primer plants’, and produce the desired changes in the soil by altering soil physical and/or chemical characteristics. An exploratory study (1) using canola (*Brassica napus* L) as primer crop on a duplex soil in south-eastern Australia produced inconclusive results and it was suggested that perennials could be more effective by virtue of their roots’ extended residence in the soil. Although several factors, such as species longevity (annuals or perennials), root characteristics and function have been associated with the priming capability of a plant specie, adaptation to the local soil conditions is of greater importance. Deep-rooting native perennial legumes should, therefore, be ideal ‘primer’ plants by increasing soil nitrogen in addition to creating biopores for soil structure improvement.

The soil ameliorative potential of acacia (*Acacia spp*) was evaluated in the current study by comparing the yield and yield components of oats following either a 6-year phase of the perennial or continuous annual cropping. The results were supplemented with simulations of wheat yields and soil water and N over several seasons to further assess long term benefits of a 6-year acacia phase.

Materials and methods

This study was undertaken at Rutherglen (36^{o} 08’S, 146^{o} 28’E) on acidic sodic brown Chromosol (Dy 3.32) consisting of a sandy to clay loam A horizon and fine sandy clay loam B horizon. Detailed descriptions of both the physical and chemical characteristics of the soil have been reported (7). Rutherglen has a high rainfall temperate climate with a mean annual rainfall of 598 mm of which 397 mm occur during the growing season (May–November) (7); the minimum and maximum temperatures average 4.3 and 17.0 ^{o}C respectively. In 1999, rainfall totalled 594 mm of which 361 mm fell during the growing season, the latter was 9 % below the long-term average; both the minimum (4.0 ^{o}C) and maximum (17.7 ^{o}C) temperatures were close to the expected.

In 1993, four belts of acacia measuring 40 m in length and seven meters wide were planted in a northwest–southeast direction across the paddock. The belts were separated by transects of at least 20 m wide which were cropped annually with rotations of cereals, legumes or oil seeds. On 10 March 1999, the acacia belts were sprayed with a non-selective herbicide (RoundUp?) and mechanically removed. On 3 May, the whole block was again sprayed with the herbicide, and on 11 May oats cv. Echidna was sown at 50 kg ha^{-1} with fertiliser that supplied 16 kg of N and 18 kg of P per hectare. Another 50 kg N ha^{-1} in the form of urea was applied on 11 June. On 2 December 1999, four one-square-metre quadrats were taken from three belts each of acacia and of the alternating continuously cropped transects. The samples were sorted into oats and weeds (mostly wild oats and silver grass) and dried to estimate above-ground dry matter (DM) and oat grain yield. The N contents of the plant and grain samples were determined. Stepped pits were dug with a backhoe to 1.5 m depth between February and March 2000 in each of the belts. Three intact soil samples (80 mm ID and 50 mm length) were taken from the exposed horizontal soil surfaces at 0.3, 0.5, 1.0 and 1.5 m depths to visually estimate pore numbers. Bulk density and volumetric water content (θ) were measured on intact soil samples taken with rings (40 mm ID and 50 mm length) from the pit face, except for depths below 1.5 m that were taken from the pit bottom. Separate intact cores were extracted away from the pits and used for chemical analyses (organic matter, CEC, mineral N, pH, EC). To explore, the influence of seasonal variability on a crop's response to soil priming by 6-year acacia phase, yield and soil N and water dynamics were simulated using APSIM models (6) for wheat (*Triticum aestivum*) cultivar Janz based on the measured soil variables. Soil water characteristics were determined in the laboratory, and the values adjusted for the two treatments based on the measured bulk density. However, the adjustments did not produce significant differences in the model outputs so the same values were used for the upper and lower limits of plant-available water for both treatments. Wheat was simulated in the absence of a well-tested model for oats and because wheat is the dominant cereal crop grown in the region; its rooting was restricted to 1.4 m depth.

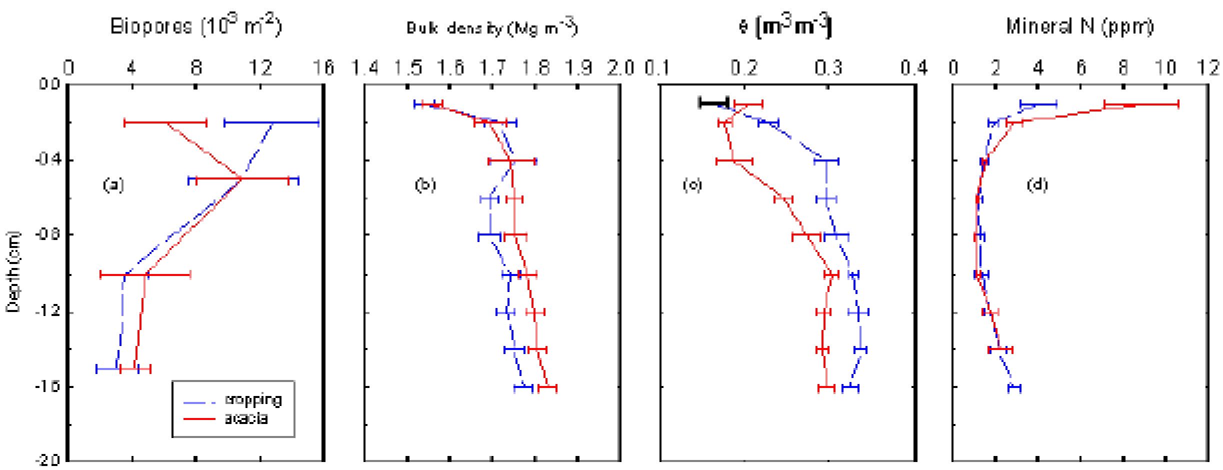

Figure 1. Soil characteristics (means ? standard errors) observed in February 2000 after seven years of continuous cropping (cropping) or six years of acacia followed by one year of cereal crop (acacia) at Rutherglen: (a) number of biopores, (b) bulk density, (c) volumetric water content (θ) and (d) mineral nitrogen.

Results and Discussion

In this study, the expected benefits of the acacia phase include increased soil porosity to enhance infiltration and root exploration by the following crop, a drier profile to minimise waterlogging and drainage, and increased soil N through fixation of atmospheric N by the acacia nodules. At 0.2 m depth of the soil (top of the B horizon), the cropping belts had more biopores (Fig. 1a) than the acacia belts indicating a greater root turn-over under annual crops in the top soil. No differences were found between the two treatments in the biopore numbers produced in the B horizon. It was observed that most of the acacia roots were yet to decay, which could primarily be associated with their thickness, and possibly high C:N, as found with other tree species (8). The soil below 0.5 m depth was consistently denser in the acacia belts compared to the cropping belts (Fig. 1b) due to shrinkage caused by excessive drying during the acacia growth, the result of which was still apparent one year after the acacia removal (Fig. 1c). Total water stored in the profile was 406 mm in the acacia belts compared with 492 mm in the cropping belts. Although, much of the difference in θ between the two treatments was in the 0.4 – 1.0 m of the soil profile, the drier and denser profile at lower depths of the acacia soil showed that the perennial had active roots well beyond those of the annual crops. In contrast with soil water, mineral N in the top 0.3 m of the profile was significantly higher for the acacia belts compared to the cropping belts (Fig. 1d); total mineral N in the 1.8 m profile was 126 and 104 kg ha^{-1} respectively. Organic matter in the top 0.4 m layer of the soil was 1.43 % in acacia belts against 1.12 % for the cropping belts.

Oat productivity and N uptake were adversely affected on the acacia belts with reductions of about 40 % in shoot N, DM and grain yields (Table 1). These yield reductions were primarily associated with the dry soil profile, which limited the ability of the crop in these belts to take full advantage of the high soil N. Significant correlations were found between θ and oat grain yield (r^2 = 0.83) and with total DM (r^2 = 0.93). Although, yield impairment associated with limited water supply at high N availability is well known (9), oat yields in the current study were further penalised by weed infestation in the acacia belts. In these belts, weeds (mostly wild oats and silver grass) constituted almost 17 % of the total DM produced, against less than 4 % in the cropping belts (Table 1). This resulted from ineffective weed control during the acacia growth, and there was a significant correlation (r^2 = 0.75) between weed DM and oat grain yield.

Table 1. Grain yield and yield components for oats and total (oat and weeds) dry matter at harvest in 1999 for acacia (acacia) or continuous annual cropping (cropping) treatments at Rutherglen.

Soil treatment	Oat DM (kg ha^{-1})	Grain yield (kg ha^{-1})	Harvest index	Grain Protein (%)	Oat shoot N (kg ha^{-1})	Total DM (kg ha^{-1})
Cropping	16971	8556	0.50	7.4	142.4	17640
Acacia	9937	5271	0.53	7.4	86.3	11977
SEM	1547.7	732.7	0.024	0.06	14.39	1168.3

A water-use efficiency of 28 kg ha^{-1} mm^{-1} was calculated if it was assumed that the total DM in the acacia belt was derived entirely from rainfall between 10 March and end of November 1999 (422 mm). The extra total DM produced in the cropping belts (5663 kg ha^{-1}) meant that there was about 200 mm more water available in these belts. Since the 200 mm was close to the available water capacity (240 mm) in the 1.8 m soil profile, the soil water must be close to the lower limit of availability in the acacia belts, and to the upper limit in the cropping belts, at the time of acacia removal. This was likely given the wet spring of 1998 and the 188 mm rainfall between November 1988 and 10 March 2000. Therefore, soil water was set at the lower limit for the acacia belts and at close to the upper limit for the cropping belts to run APSIM from 11 March 1999 to 20 February 2000 while simulating wheat during the 1999 winter. At the end of simulation, estimated stored soil water was 406 mm for the acacia belts and 494 mm for the cropping belts consistent with the observed data. Simulated wheat grain yield was reduced by the same order of magnitude (40 %) in the acacia belts (Table 2) as measured for oat in the field (Table 1).

Table 2. Wheat yield simulated using soil data in Figure 1 for model initialisation in 1999, and in 1988, 1984 and 1977 that had median values for the wettest, average and driest 33 % of the 33 years (1967 to 1999) of rainfall. Numbers in parenthesis are cropping season rainfalls.

Soil treatment	1999	1988	1984	1977
Cropping	6013	5540	6138	3219
Acacia	3617	5958	1567	1169
Rainfall (mm)	*594 (361)*	*806 (520)*	*598 (356)*	*402 (275)*

Using the lower water limit for the acacia treatment and upper limit for the cropping belts along with measured N (Fig. 1) and soil carbon to initialise the model from 10 March of each year, it was possible to simulate the first season wheat after acacia removal. In wet years such as 1988, predicted wheat yield could be almost 8 % higher following acacia than in continuous cropping (Table 2). In years with average (1984) or below average (1977) rainfall, predicted yields were reduced by up to 74 % in the acacia belts compared with cropping belts. A continuous simulation of wheat over five years (1995 to 1999) allowed the influence of the differences in soil water and soil N between the two treatments to be examined over an extended period of time. Simulated grain yields were similar for the two treatments (Table 3) in the first year due to exceptionally wet season. From the second year onwards, soil water was similar for the two treatments, but soil N was higher in the acacia belts where the grain yield was increased by between 3 and 26 % compared to the cropping belts. Thus, the water deficit existing after acacia was overcome within two years during a succession of wet seasons, while yield levels are maintained or even improved without the hazards of deep drainage. In this high rainfall environment, the loss of up to 24 % of annual rainfall through drainage in wet years with continuous cropping (Table 3) could be greater on coarsely textured soil where it could be as high as 36 % (2).

Table 3. Simulated wheat grain yield, mineral N and water in the soil on 1 May, and evapotranspiration (ET) and drainage during the year, for soils previously under either continuous cropping (CC) or acacia (AC). Annual (and growing season) rainfalls are also given.

Variables	1995		1996		1997		1998		1999	
	CC	AC	CC	AC	CC	AC	CC	AC	CC	AC
Yield (kg ha^{-1})	5078	4918	2617	3049	3864	3972	3900	4893	4177	4449
N (kg ha^{-1})	145	166	44	86	61	95	56	91	59	74
Water (mm)	553	369	517	486	524	547	462	466	504	503
ET (mm)	483	455	527	485	439	431	497	509	521	518
Drainage (mm)	178	0	148	0	10	0	0	0	0	0

Rain (mm)	774 (543)	620 (422)	399 (309)	517 (389)	594 (361)

The trends in grain yields between the two treatments were congruent with measured yield data for wheat and canola grown either in continuous annual crop rotations or after a short phase of lucerne in the same years on an adjacent block (4). Drainage simulated for the cropping belts in 1996 (Table 3) was similar to 143 mm calculated for a similar treatment in the adjacent block (7), while the estimated wheat yields in 1999 (Table 2) and in 1995 (Table 3) were close to the measured of 5880 and 5550 kg ha^{-1} for cv Janz. The consistency of the simulations with observation provided some degree of validity of the model estimates, even though this is not a modelling study *per se*.

Conclusions

Excessive soil drying during six years of acacia growth caused compaction and reduced water availability, which penalised the following cereal crop in years with average or below average rainfall. In years with above-average rainfall, the acacia soil increased simulated crop yield due to improved soil N, and prevented drainage, for up to five years. Poor weed control during years of acacia growth caused significant yield reductions in the following crops.

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