Increasing rainfall-use efficiency for dryland crops on duplex soils

Sale P[1], Gill J[1], Peries R[2], Tang C[1]
[1]Department of Agricultural Sciences, La Trobe University, Melbourne Campus Vic. 3086, Australia; P.Sale@latrobe.edu.au
[2] Department of Primary Industries, PO Box 103, Geelong, Vic. 3220, Australia.

Keywords: Subsoil manuring, plant available water capacity, Sodosol

Introduction

Plant available water in soil is a key driver for crop production in water-limited environments. This is particularly apparent for large grain-growing areas of southern Australia where rainfall-use efficiency is restricted by subsoil constraints. Many of these soils have texture-contrast profiles, where lighter-textured topsoil, from sandy-loam to loamy-clays, overlies dense clay subsoil. These are the duplex soils that are classified in the Australian soil classification system as Sodosols, Chromosols or Kurosols (Isbell 2002). These soils in general, and Sodosols in particular with sodic subsoils, have low plant available water capacity (PAWC) because the clay subsoil has a low proportion of meso-pores and low hydraulic conductivity, so little rainfall can infiltrate into the B horizon. Furthermore the low macro-porosity and high soil strength of the clay, mean that root penetration and exploration into the clay subsoil, and water extraction from the clay, are restricted. Such soil problems are not limited to southern Australia as there are large areas of alfisol soils, where dense clay subsoils can occur (Kalpage 1974) and constrain crop yields.

This paper reports on a field experiment on a Sodosol soil in the high rainfall zone of south west Victoria in Australia, that set out to improve the physical properties of the dense, clay subsoil at the site. We postulated that an improvement in the physical properties of the clay subsoil would enable roots to penetrate and extract water and nutrients from the subsoil, and this would then enable more rainfall to infiltrate and be stored in the clay subsoil. The approach taken was to incorporate different organic and inorganic amendments into the top of the clay B horizon; such interventions have previously been rejected because of the cost associated with such deep intervention. The practice involving the incorporation of high rates of organic amendments in the subsoil with deep ripping, has now been termed 'subsoil manuring' (Gill et al., 2009)

Materials and Methods

This study involved 2 consecutive wheat crops grown in 2005 and 2006 at a field site at Ballan in south west Victoria. The site was a paddock under permanent raised beds that had been under continuous cropping (canola-wheat-barley-wheat-canola) for the last 8 years. The 2005 year received normal rainfall with 170 mm of spring rainfall, whereas 2006 was a drought year with only 74 mm falling during the spring months. The experimental design was a randomized block with 9 treatments in 4 replicated blocks. We report on 4 treatments: a control, deep ripping (to 40 cm), and the deep incorporation of gypsum at 10 t/ha, and lucerne pellets (2.8 %N, 0.9 %P, 1.4%K) at 20t/ha, at a depth of 30-40 cm in the subsoil. The amendments were applied manually through a pipe attached behind a deep ripper. There were two rip lines, 80 cm apart, on each 1.7-m bed (centre to centre). Soil properties, crop management details and site information are described in Gill et al., (2008). These data show an increasing clay content, bulk density, and sodicity and decreasing hydraulic conductivity and macro-porosity, with depth. The treatments were applied one week before wheat (*Triticum aestivum* var. Amarok) was sown in early May 2005. The same crop was sown in late May in 2006. Grain yields were determined from plants harvested in 0.5 m^2 quadrats taken on the top of the bed. Grain protein percent was determined by analyzing the grain for N using an Elementar Vario analyzer, and multiplying by 6.25. The volumetric water content (θv, v/v %), in 20-cm soil layers from the depth of 20 to 80 cm, was determined when the wheat crop was sown in 2005 and 2006, and at crop maturity in December 2005 and 2006, using a calibrated Neutron Probe. The soil water in layers was expressed in mm using the calculation [θv (%) x depth (mm)]/100.

Results and Discussion

There were marked improvements in grain yields with the subsoil manuring treatment (lucerne pellets), in comparison to the control for the first 2 crops following the subsoil intervention (Table 1). An additional 5.3 t/ha of wheat grain was produced in 2005, representing a 70% yield increase, while an extra 1.9 t/ha yield increase represented a 53% gain in the 2006 drought year. In both years the lucerne amendment resulted in grain protein concentrations in excess of 13%, and these are attributed to the high N status of the subsoil-manured plots due to the added N in the amendment. There was no benefit from deep ripping or added gypsum on grain yield or grain protein concentration compared to the control plants.

The increased grain productivity with subsoil manuring can be explained by the improved water supply to the wheat crops, and to improved supply of nutrients from the organic amendment. More water was extracted from the 40-60 and 60-80 cm subsoil layers in 2005 and 2006 by wheat plants in the subsoil manured treatments, compared to the controls (Table 2). The increases amounted to 2-3 fold increase in the 40-60 cm layer, and a 3-4 fold increase in the deeper 60-80 cm layer. Deep ripping resulted in close to a 60% increase in crop extraction in 2005 compared to the control, but this difference had disappeared in 2006. It is likely that additional water was extracted below 80 cm but this was not measured.

The subsoil manuring treatment also increased the water accumulation in the 40-60 and 60-80 cm subsoil layers during the summer-autumn fallow period in 2006. The effect was most marked in the deeper layer where there was a more than 12-fold increased in storage and capture of summer rainfall into this 60-80 cm layer, compared to the control treatment. This marked improvement in the capacity of subsoil layers to accumulate and store rainfall can be attributed to the improvement of soil structure and the increase in hydraulic conductivity in the upper layers of the clay subsoil with subsoil manuring (Gill et al., 2009). In addition, the 2005 wheat crop had extracted an extra 90 mm of water from the 40-80 cm layer, thereby ‘creating space’ for storing the extra water in the subsoil. Thus the subsoil manuring intervention increased the PAWC of this sodosol profile, and greatly increased the rainfall use efficiency in both favorable growing seasons and drought years. The outcome is a trade-off between the energy required to undertake the subsoil intervention, and the carbon and nutrient inputs in the organic amendment, in return for improved water use.

Table 1. Treatment effects on grain yield (t/ha), harvest index, and grain protein (%) for two successive wheat crops in 2005 and 2006.

Treatment	2005			2006		
	Grain yield (t/ha)	Harvest Index	Grain Prot. (%)	Grain yield (t/ha)	Harvest Index	Grain prot. (%)
Control	7.6	0.54	9.1	3.6	0.50	10.8
Deep-ripped	8.0	0.63	9.2	4.2	0.58	11.1
Gypsum	8.5	0.53	8.5	3.8	0.51	10.6
Lucerne pellets	12.9	0.64	13.4	6.5	0.50	13.9
LSD (P=0.05)	1.8	0.09	0.9	1.6	ns	1.8

ns, not signifiant

Table 2. Treatment effects on changes in soil water (mm) in subsoil layers during the cropping cycle in 2005 and 2006, due to crop extraction and fallow accumulation.

Period of the crop cycle	Soil layer (cm)	Soil water (mm) Control	Deep-ripped	Gypsum	Lucerne	LSD (P=0.05)	P-value
2005	20-40	33.0	40.8	22.2	32.6	12.6	0.03
Crop extraction from	40-60	11.8	25.1	13.9	40.0	11.4	0.008
sowing to harvest	60-80	12.6	27.2	14.8	50.6	8.6	<0.001
	TOTAL	57.4	93.0	50.9	123.2	26.3	<0.001
2006	20-40	30.6	41.8	41.5	36.8	-	>0.05
Fallow accumulation	40-60	10.9	10.4	16.7	43.4	15.1	0.04
- harvest to sowing	60-80	3.5	15.2	16.5	44.8	15.7	<0.001
	TOTAL	45.0	67.4	74.7	125.0	27.8	<0.001
2006	20-40	22.3	28.8	29.4	34.9	11.2	0.03
Crop extraction from	40-60	24.3	20.2	32.5	46.7	12.8	0.005
sowing to harvest	60-80	17.5	18.2	33.2	54.0	10.5	<0.001
	TOTAL	64.0	67.8	95.1	135.6	28.7	<0.001

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