Management to improve soil productivity and maximise lateral infiltration in permanent bed-furrow irrigation systems

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Introduction

The practice of conservation agriculture has been accepted for some time as conventional wisdom for improving soil conditions and raising the soil organic carbon levels of cropping land. This has been complemented over the past 10 years by controlled traffic agriculture, which has further improved soil management practices by almost eliminating compaction as a form of soil degradation.

Notwithstanding the improved soil conditions that result from the practice of controlled traffic conservation agriculture, soils minimally tilled by such practices are still subject to consolidation through wetting and drying cycles. In this paper we report on a technique that further improves on these conservative soil management practices. This technique loosens soil at depth without any inversion, and we examine the consequences this has on the proliferation and distribution of roots, the contents and distributions of soil organic carbon and total soil nitrogen, the productivity of cropping soils and the lateral infiltration of irrigation water in permanent bed-furrow systems. Results are drawn from experimental sites in Western Australia, Queensland and Pakistan.

Materials and Methods

The Western Australian component of this research was undertaken on rainfed field crops on two soil types, a hardsetting grey clay at Mindarabin and a waterlog-prone texture contrast soil at Woodanilling. The Mindarabin soil has dispersible A and B horizons; the A-horizon is a shallow (~80mm deep) and hardsetting; fine sandy loam and the B-horizon is a dense clay (bulk density ~1,800kg/m^3) with a high penetration resistance (average seasonal value of > 1,800kPa). The Woodanilling site has a sandy loam A-horizon and a very dense clayey B-horizon (bulk density ≥ 1,800kg/m^3) at ~150mm depth. The cropping systems evaluated at Mindarabin were tri-replicated plots of 1ha, with a control that had each season's crop established by no-tillage (NT) practices, and treatment plots whose crops were established by no-tillage practices on seedbeds loosened to a depth of ~250mm without inverting any soil (BL). The crops at Woodanilling were tri-replicated plots of ~3ha on permanent beds, with each season's crop established by no-tillage (NT). The control beds consolidated after the deep cultivation required to install them. The treatment beds were loosened at a depth of ~250mm prior to seeding each crop (BL).

The Pakistan research was undertaken at Mardan on a uniform fine sandy clay loam, on tri-replicated plots. The control plots were flood-irrigated, with no-tillage established crops (NT). The treatment plots were furrow irrigated permanent beds that were blade-loosened to a depth of ~250mm prior to sowing each crop by no-tillage practices (BL).

The Queensland research was undertaken on a deep uniform self-mulching clay at Cambooya., south of Toowoomba. The treatments were imposed on irrigated tri-replicated plots of permanent beds. Crops on the control treatment were established by no-tillage (NT) on beds that consolidated after the deep cultivation required for their installation. Crops on the BL treatment were established with a no-tillage seeder on beds loosened to a depth of 250-300mm (BL) prior to seeding. Two seasonal irrigations were applied.

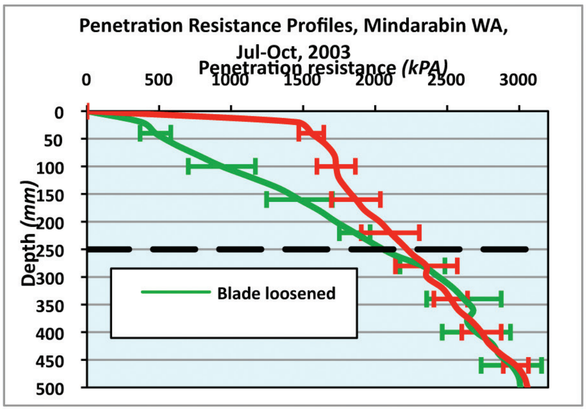
At all sites blade loosening to about 250mm was undertaken in a controlled traffic regime immediately prior to seeding, with the blade tines positioned in the inter-row spaces of the previous crop. The blades are mounted horizontally on both sides of narrow tines, and are 10mm thick and 200mm wide at the tine and 80mm wide at the tip. The length of the blades is adjusted to match bed width so that only two pairs of blades are needed to cut the full width of permanent beds.

The experimental measurements undertaken at these sites were: (i) Mindarabin: monthly profiles of penetration resistance (penetrometer), monthly profiles of moisture content (capacitance probe), root mass profiles (gravimetric) , and whole-plot grain yield; (ii) Woodanilling: whole-plot grain yield and organic carbon and total nitrogen profiles at the end of a six-year experimental program; (iii) Mardan: root mass distribution (number/grid and gravimetric) and whole-plot grain yield; (iv) Cambooya: hand-sampled sub-plot grain yields, irrigation application rate, bulk density at sowing and harvest, and 0-1,000mm soil moisture profiles during the irrigation events at zero, 330, 667 and 1,000mm distance from the centre of furrows on 2-metre spaced beds. All soil measurements were tri-replicated within the tri-replicated treatment plots.

Results and Discussion

Seasonal soil penetration resistance

The average July to October penetration resistance (PR) profiles for 2003 at Mindarabin (Figure 1) show the deepened seedbed treatment had significantly lower PR for the 0-240mm depth ($P<0.05$, n=210/ sampling depth). Below this depth PR differences between treatments were not significant. The 2003 average moisture profiles for the June-August period at this site (Figure1) show significantly less water in the deepened seedbed treatment to a depth of 300mm ($P<0.05$, n=108/sampling depth). These differences illustrated greater evapotranspiration and less drainage of soil-water from the deepened seedbed compared to the NT profile. Importantly, the average moisture content in the NT profile contained 14mm more water than the BL profile and was waterlogged below 150mm for the entire three months.



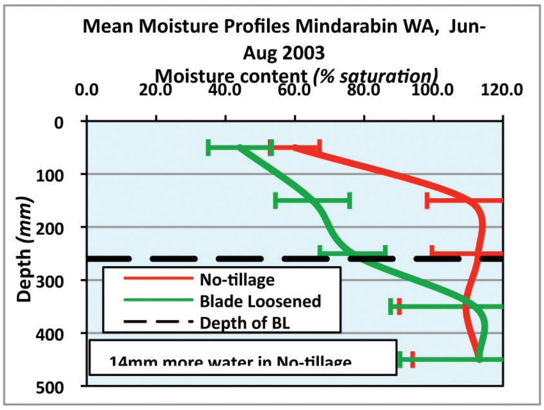


Figure 1. The effects of blade loosening at 250mm depth on average penetration resistance (left) and moisture content (right) profiles in Blade loosened and No-tillage seedbed treatments at Mindarabin during winter and early spring 2003. Horizontal bars are ± one standard deviation (SD).

Root growth and distribution

Data of the distribution of roots in NT and BL seedbeds at Mardan and Mindarabin WA (Figure 2) are presented as per cent at each depth relative to the 0-400mm total of root numbers at Mardan, and root mass at Mindarabin. The Mardan data are from maize and wheat crops, and the Mindarabin data are from wheat only. The data were combined because the root distribution profiles for both sites and crop types had the same shape and magnitude of differences. Significantly more roots were found in BL treatment (28% more) in the 0-400mm depth interval ($P<0.05$, n=54), and 90% of this increase occurred in the 100-300mm depth interval. These increases in the growth and proliferation of roots in soils with lower PR profiles agree with the detailed studies of many researchers (e.g. Gregory, 2006).

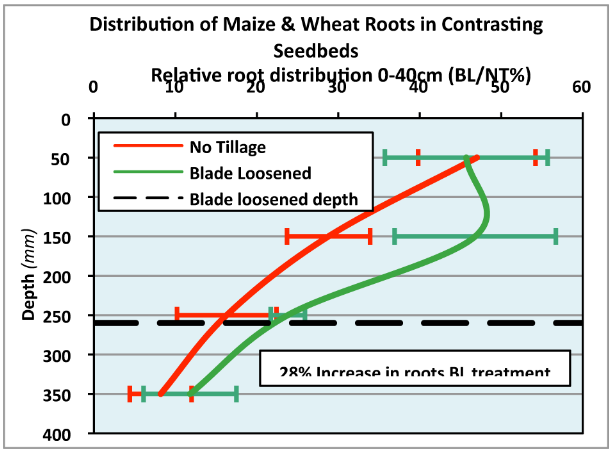


Figure 2. Root distributions of maize and wheat crops grown on No-tillage and Blade-loosened seedbeds. Horizontal bars are ± one SD.

Soil organic carbon and total soil nitrogen

Figure 3 shows mean soil organic carbon and total soil nitrogen profiles at Woodanilling after six years of no-tillage cropping on permanent beds that were consolidated (NT) and blade loosened at 250mm depth prior to seeding each crop (BL). The mean profiles of each treatment are significantly different at all of the sampling intervals, 0-100, 100-200, and 200-300mm ($P<0.05$, n=81). The BL treatment resulted in 0-300mm profile increases of 29% organic carbon and 37% total soil nitrogen. These results are consistent with the results of increased root mass distribution found in blade loosened treatments at Mindarabin and Mardan. Increased root mass and the retention of undisturbed roots from previous crops provide an increased food supply for soil organisms, which increases their population size and hence, the amount of organic soil nitrogen.

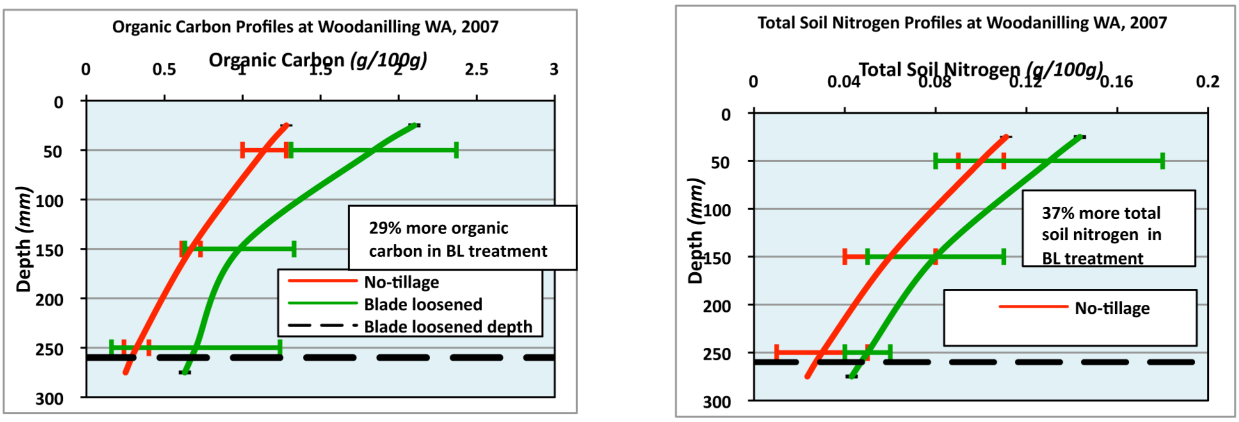


Figure 3. Profiles of soil organic carbon (left) and total soil nitrogen (right) after six years of cropping on permanent beds at Woodanilling WA, in NT and BL seedbeds.

Yield

The improved soil conditions created by the practice of blade loosening improved soil productivity at all sites. The Pakistan yield data (2004-2007) for wheat and maize crops showed the BL treatment produced significant yield increases of 12-16% ($P<0.05$, n=57) over those of the NT treatment. The WA yield data for wheat, barley, oats, peas and canola showed BL treated soils produced significant yield increases of 13-46% ($P<0.05$, n=84) (Hamilton and Bakker 2002, Hamilton et al. 2005(a,b) and Hamilton 2007). Such yield increases are the consequence of the BL treatment facilitating increases in root mass, soil carbon and nitrogen contents and improved structure and stability of structure, the last of which was illustrated by bulk density data collected at all sites. For example, at Cambooya, Qld, growing seasonal settlement of the 0-300mm depth of soil in the BL treatment in 2011/12 was significantly less than that in the NT treatment. The BL treatment BD at seeding was 0.98g/cm^3 and 1.06 g/cm^3 at harvest, while the comparable data for the NT treatment were 1.03 g/cm^3 at seeding and 1.16g/cm^3 at harvest ($P<0.05$, n=82) (Akbar 2013).

Lateral and deep infiltration

At Cambooya, Qld, two furrow irrigation events in 2011-12 demonstrated the benefits of the greater porosity and more stable structure of soil in the BL treatment. These irrigations had quite different antecedent moisture conditions, 0.28mm^3/mm^3 and 0.16mm^3/mm^3. In the more moist conditions lateral infiltration was slower, and in both moisture conditions the lateral infiltration in the BL beds was much faster than in the NT beds. In the more moist soil conditions infiltration to the centre of the BL beds occurred at 57% of the time needed in the NT beds, and in the drier soil conditions, at 42% of the time needed in the NT beds (Figure 4). In fact, the infiltration behaviour of the 0-300mm depth of soil in both treatments was entirely consistent with horizontal infiltration theory (Philip 1969). Cumulative infiltration proceeded with the square root of time, and sorptivity was larger in both the better-structured and drier soil conditions.

The practical and economic benefits for irrigation practice of BL-managed soils were illustrated by (i) the shorter time required to wet the BL beds to their centre, and (ii) the distribution of water in the profiles beneath the beds at the time water reached the centre of the BL beds. At this time the full width of the BL beds and the whole of the 0-1,000mm profile had saturated. In contrast, the beds and the profile beneath the beds of the NT treatment were unsaturated (Table 1). The more rapid infiltration to the centre of the BL beds produces more uniform wetting and requires less water and shorter irrigation applications. The application of water to NT beds requires irrigations to last two to three times longer and risks excessive deep drainage losses because of the preferential vertical infiltration in soils managed in this manner.

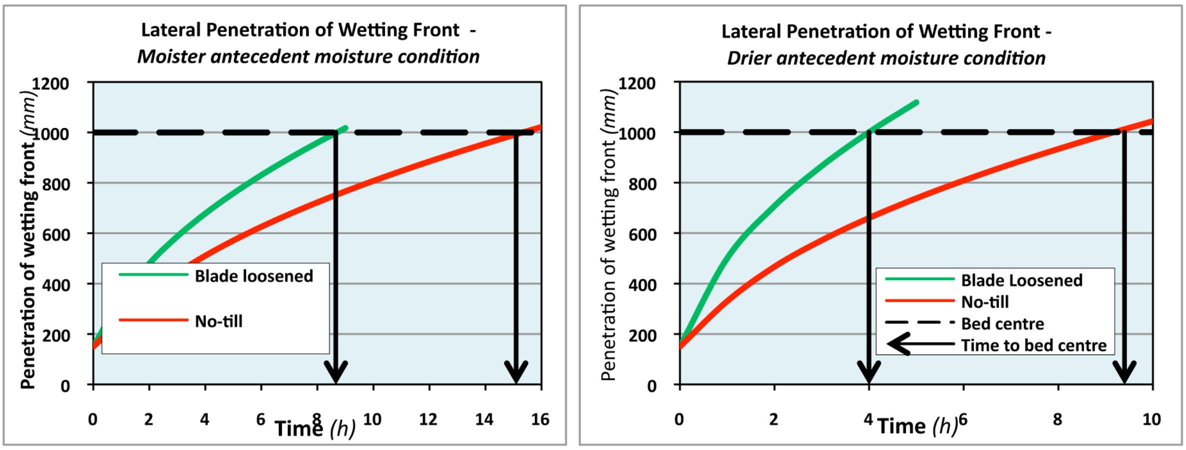


Figure 4. Lateral penetration of wetting fronts from furrow irrigations on permanent beds at Cambooya, Qld. Antecedent soil moisture was greater at the 1st irrigation (left) than at the 2nd (right).

Table 1. Percent saturation of NT and BL treated soils when wetting front reached the BL bed centre

Irrigations in 2011/12	Soil layer depth (mm)	Treatments	
		NT	BL
First	0-300	82%	100%
	300-1000	84%	100%
Second	0-300	68%	100%
	300-1000	86%	100%

Conclusion

Wherever the practice of deep blade loosening has been used to supplement conservation agriculture practices and controlled traffic farming it has delivered additional improvements to the soil carbon, total soil nitrogen, soil aggregation, stability of soil aggregates, improved lateral infiltration and soil productivity. These additional improvements are the consequence of near-undisturbed retention of crop roots and their associated soil biota that create and stabilise, loose soil conditions, which, in turn, facilitate increased root growth and proliferation. Importantly, these additional soil improvements have been measurable in terms of increased production and more effective and potentially more efficient furrow irrigation.

Acknowledgements

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