A comparison of the impact of 14 years of conventional and no-till cultivation on physical properties and crop yields of a loam soil at Grafton NSW.

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Abstract.

The impact of 14 years of continuous conventional (CT) or no-till (NT) cultivation on surface soil structure and crop yields were examined on a loam soil at Grafton in N.S.W. During the earlier years of the trial, soil porosity and crop yields were not greatly effected by the different tillage techniques. At the end of the trial, however, soil porosity, stability, and crop yields were greatest under NT.

Measured increases in soil macroporosity, and stability under long term NT were consistent with higher saturated hydraulic conductivity, plant available water, water use efficiency, and crop yields. The improvement in soil structure observed under NT is believed to have been the major contributor to the sustained improvement of crop yields.

Introduction.

Past research into the long term effects of cultivation upon soil physical properties, has yielded many apparently contradictory results (Lal et al 1989). Tillage effects on soil properties are usually site specific and depend upon the interaction of soil and climatic conditions, with soil and crop management practices.

Under non-limiting conditions, the availability of water to crops is largely determined by soil porosity. Tillage immediately increases the total porosity of soils (Hamblin 1984; Lindstrom and Onstad 1984) through the creation of a few strongly irregular macropores (Pagliai et al 1984). However, prolonged continuous conventional tillage (CT) reduces soil porosity through the mechanical obliteration and compaction of structure, and the gradual degradation and loss of the soil organic matter which stabilises soil aggregates against slaking, dispersion, and collapse. Significant tillage-induced structural degradation of loam soils can occur as early as 3 (Burch et al 1986) to 5 years (Hamblin 1984) after the commencement of cultivation, and is typically associated with reductions in crop yields.

By contrast, the prolonged use of continuous no-till (NT) has been shown to gradually improve the stability, macroporosity, and crop yields of loam soils over time (Hamblin 1984; Unger and Fulton 1990). Within a NT system soil porosity develops through the actions of the soil biota, which typically occur in higher densities under NT. For example, Chan and Heenan (1993) found a significant correlation between the increased macropore incidence and the greater earthworm population densities found in the soil under extended NT.

Methods.

An experimental field trial was conducted at a site in Grafton, NSW, which had previously been under pasture for at least 5 years. The soil at the site had weakly structured loam A horizons (0-30cm), which abruptly graded into more strongly structured clay loam (to medium heavy clay at depth) B horizons. These soils have been variously classified as red/yellow Podzolics (Stace et al 1968), Kurosols (Isbell 1992), or Ultisols (Soil Survey Staff 1975).

The experiment began in 1981, and consisted of two tillage treatments (CT and NT) within a summer soybean and winter cereal crop rotation. Each treatment was replicated 3 times and each replicate consisted of a field plot measuring 60m long x 20m wide. NT treatments were never disturbed apart from the sowing operation, whereas CT treatments were chisel ploughed to a depth of 20cm and disk harrowed between each crop. Superphosphate was applied at a rate of 400kg/ha four weeks prior to the sowing of the soybeans, and an additional 100kg/ha was applied at sowing. Potash was used in some years at rates of up to 100kg/ha, and Molybdenum was applied as a seed dressing. A four row direct drill planter was used on both treatments.

Soil samples were collected to a depth of 50cm to determine soil bulk density, and also structural stability using the wet sieving and percentage dispersible silt and clay techniques. Soil water potential data were obtained using the pressure plate technique and intact soil cores. Soil strength measurements were made in the laboratory using intact soil cores and a laboratory penetrometer, following a series of unsuccessful attempts at measuring strength in the field. Saturated and unsaturated (4cm suction) hydraulic conductivity were measured in the field using disc permeameters, and crop water use was determined using a neutron moisture meter.

A rainfall event with an intensity of 80mm/hr was simulated in the field to assess the infiltration and runoff characteristics of the soil. Soil cores were collected before and after the simulation to examine the redistribution of infiltrated water.

Results and Discussion.

Although some deeper measurements were made, the majority of the significant treatment effects were detected within the surface 20cm of the soil profile. Previous work at the site by Harte and Desborough (1985) and Thompson (1986) found that the soil bulk density was not greatly effected by tillage during the early years of the trial. However, recent data has shown that the NT surface soil has a significantly lower bulk density than the CT surface soil.

Table 1 : Soil physical properties in year1 (Y1) and year14 (Y14) of the cropping phase

Physical Property of the Soil		No Tillage	Conventional Cultivation	l.s.d.	Prob %
Bulk Density (g/cm^3)	Y1 0-10cm*	1.38	1.34		
	Y14 0-10cm	1.13	1.37	0.07^+	0.01
	Y1 10-20cm*	1.51	1.46		
	Y14 10-20cm	1.36	1.44		
	Y14 20-30cm	1.37	1.40	n.s.	
	Y14 30-40cm	1.31	1.36	n.s.	
	Y14 40-50cm	1.24	1.30	n.s.	
Percentage organic matter **	Y14 0-10cm	3.37	1.65	n.a.	
Dispersible silt and clay %	Y14 0-10cm	16.3	23.6	6.2	0.01
Dispersible clay %	Y14 0-10cm	0.6	1.9	0.9	0.01
Mean Weight Diameter (mm)	Y14 0-5cm	4.48	0.83	2.08	0.01
	Y14 5-10cm	2.73	1.10	1.37	0.05
Hydraulic Conductivity (mm/hr)	Y14 sat	189.4	28.0	75.5	0.01
(surface 10cm only)	Y14 unsaturated	2.3	10.8	7.8	0.05

* from data of D.Thompson (1986) ** from data of N.Dacquiado (1994) (Pers Comm)
+ l.s.d. for bulk density data are valid across time, depth, and treatments.

The bulk density of the CT surface soil did not change greatly over the 14 years of the experiment, whereas it has significantly decreased in the NT surface soil. This indicates that the dominant treatment effect was the development of porosity occurring under NT. The higher organic matter content of the NT surface soil (see Table 1) supports this conclusion, as it is typically associated greater biological activity.

Soil bulk density below a depth of 20cm was consistently greater under CT than under NT. Although not statistically significant, the consistency of the data suggests that sub-surface (below 20cm depth) compaction may have occurred under CT and not under NT.

The dispersible silt and clay, dispersible clay, and mean weight diameter data shown in Table1 indicate that the NT surface soil was more stable and aggregated than the CT soil. These differences in stability are consistent with differences in the soil organic matter contents under the different treatments. The collapse of the larger unstable aggregates, and the associated increase in the smaller aggregate sizes, as shown in Figure1, contribute to the lower porosity and greater bulk density of the CT surface soil.

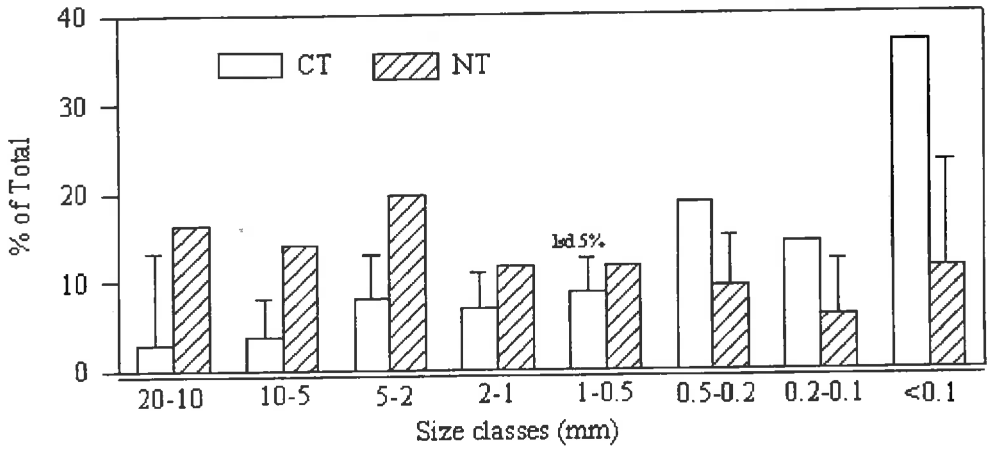

Figure1 : Proportion of total aggregates in each size class.

The NT surface soil had a significantly higher saturated hydraulic conductivity (K_{sat}) and a significantly lower unsaturated hydraulic conductivity (K_{unsat}) than the CT surface soil. The difference between K_{sat} and K_{unsat}, is due to the contribution of macropores with a diameter >0.8mm (transmission pores) to K_{sat}. The difference measured between K_{sat} and K_{unsat} was greatest for the NT soil, and is consistent with the data of Chan and Heenan (1993).

As a result of the observed effects on soil porosity, soil water release characteristics were also effected by tillage (see Table 2). The soil water content at wilting point (ψ_m=-1.5 MPa) was not significantly different between the two treatments. However, at field capacity (ψ_m = -0.01MPa) and at saturation (ψ_m = 0 MPa) NT had greater water contents.

Table 2 : Water potential data for the CT and NT soils (Y14) (cm^3/cm^3)

Matric potential (MPa)	**CT 0-5cm**	**NT 0-5cm**	**CT 5-10cm**	**NT 5-10cm**	**CT 10-20cm**	**NT 10-20cm**
0 (saturation)	0.40^{a}	0.61^{b}	0.47^{a}	0.50^{a}	0.53^{a}	0.51^{a}
-0.01 (field capacity)	0.27^{c}	0.36^{d}	0.37^{b}	0.42^{b}	0.42^{b}	0.40^{b}
-1.5 (wilting point)	0.06^{e}	0.11^{e}	0.21^{c}	0.22^{c}	0.24^{c}	0.23^{c}
0-0.01 (drainage) (mm)	6.5	12.5	5.0	4.0	11.0	9.0
0.01-1.5 (available water) (mm)	10.5	12.5	8.0	10.0	18.0	17.0

($^{a\,b\,c\,d\,e}$ are significantly different at P<0.05 within each depth interval)

The greater number of macropores within the surface of the NT soil resulted in a significantly greater amount of water between the matric potentials of 0MPa and -0.01MPa, and also -0.01 MPa and -1.5 MPa. This is consistent with the higher hydraulic conductivity of the NT soil, and suggests that water infiltration and redistribution characteristics of NT surface soil are superior to those of the CT surface soil. As a result the ability of NT surface soil to readily transmit water, the overall potential of the NT profile to store and provide water for crops was superior to that of CT profile.

Soil strengths above 2000kPa are thought to impede root extension and the data in Table 3 show that at a matric potential of -1.5 Mpa the overall strength of the CT surface soil was greater than that of the NT soil, and that it also exceeded 2000kPa. The combination of lower plant available water holding capacity and greater soil strength suggests that root extension may have been inhibited to a significantly greater extent under CT. Unfortunately root sampling was not conducted.

No significant differences in soil strength were detected between the treatments at matric potentials of 0 MPa (saturation) or 0.01MPa (field capacity)

Table 3 : Soil strength (kPa) under CT and NT at a matric potential of -1.5Mpa (Y14)

Depth	CT	NT	Avg
0-5cm	1874^{a}	1236^{a}	$1555^{a''}$
5-10cm	2898^{a}	1927^{a}	$2413^{b''}$
10-20cm	3709^{a}	2234^{a}	$2972^{c''}$
Avg	$2827^{a'}$	$1799^{b'}$	

($^{a\,b}$ are significantly different at $P<0.05$)

Under simulated rainfall, the steady state infiltration rates of CT plots were significantly lower than those of NT plots (5mm/h and 25mm/hr respectively). These infiltration rates were consistent with the redistribution data, which found that, after the simulation, the water contents of the NT and CT soil profiles had increased by 27mm and 13mm respectively. A reduction in infiltration typically results in greater runoff and soil loss and the calculated soil losses during the simulation were equivalent to 12.1t/ha and 2.6t/ha under CT and NT respectively.

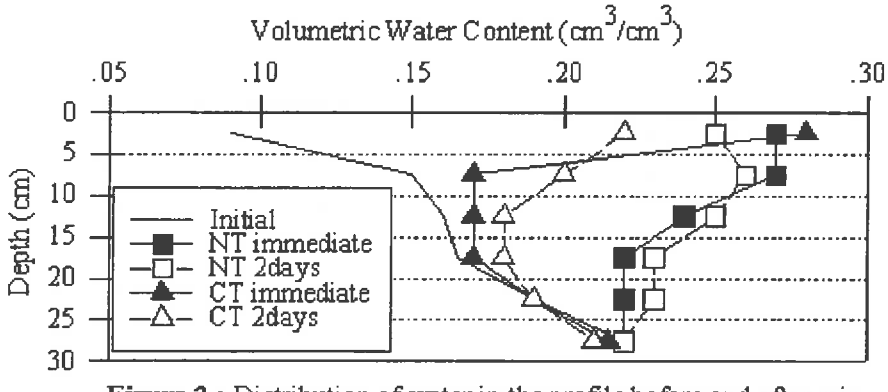

Figure 2 : Distribution of water in the profile before and after rain.

Immediately prior to the simulation, the initial soil profile water contents of the two treatments were not significantly different, and were plotted as a single line (see Figure 2). Immediately after the simulation, water had penetrated to depths of 25cm and 15cm for the NT and CT treatments respectively. Two days later infiltrated water had moved further into the profiles of both treatments.

Surface sealing was observed on CT soil under rapid wetting. The associated reduction in surface soil porosity would have contributed to reduced infiltration and increased soil loss of the CT soil. Similar results have been reported by Chan and Mead (1988), and Burch et al (1986).

A blanket of decaying plant residues, fungi, mosses, and lichens covered the NT soil, whereas the CT soil was sealed with a bare hardsetting erosional crust. Seedling counts of 14 plants/m^2 under CT, and 36 plants/m^2 under NT were taken during the establishment of the soybean crop, these differences are consistent with the greater strength of the CT surface soil when dry.

The relationship between crop yields and tillage practices has changed over time. As shown in Figure 3, the annual soybean yields of the NT treatments between 1981 and 1985 were consistently less than or equal to those resulting from CT (averages of 2.46t/ha and 2.82t/ha respectively). CT was unable to sustain these higher yields indefinitely, and from 1987 onwards the yields of the NT treatments were typically greater than those of the CT (averages of 2.14t/ha and 1.67t/ha respectively).

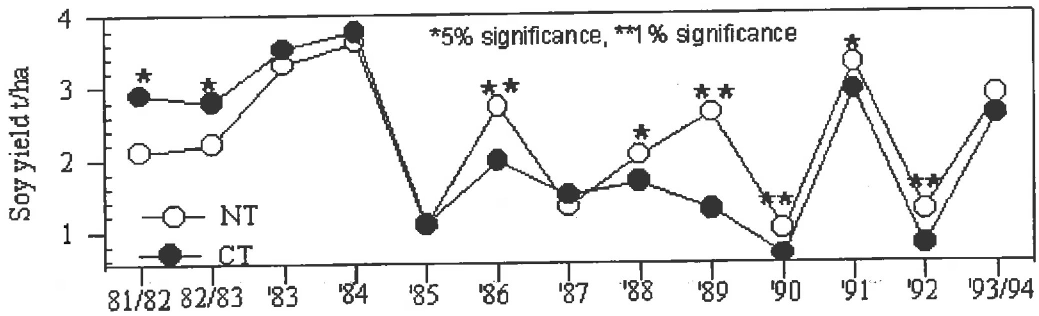

Figure 3 : Soybean yield during trial history

During the final cropping cycle of the trial, apparent total water use (the difference between the total profile water content at beginning and end of crop, plus total rainfall) and crop yield were examined. The dry matter yield, grain yield and the associated apparent water use efficiencies (WUE) of the winter oats crop were greatest under NT (see Table 4). Similar results were obtained from dry matter sampling during the following soybean crop, however, low rainfall and extensive pest damage during the growth of the soybean crop confounded the final yield data for both treatments.

The large differences between the calculated WUE of the treatments suggests that water is being lost from the CT system due to factors other than crop uptake.

Table 4 : Crop water use, and yield data for the soybean and oats crops

Crop and Treatment		Dry Matter @ 8o days t/ha	Total Water use mm	Water use efficiency kg/ha/mm	Grain Yield kg/ha	Total Water use mm	Water use efficiency kg/ha/mm
Oats	**NT**	5.72	97.2	**58.8**	661	97.2	**5.2**
	CT	4.45	97.1	**45.8**	290	97.1	**2.2**
Soy	**NT**	2.61	121.7	**21.4**	-	-	-
	CT	1.74	125.3	**13.9**	-	-	-

During the last soybean crop, areas of the field plots were intentionally cleared to measure the infiltration and evaporation of rainfall under the prevailing field conditions. Water use data taken from these areas indicated that reduced infiltration and increased evaporation contributed to the greater apparent water use of the CT treatments. Over 22 days in March 1994 a total of 68.9mm of rain fell at the experimental site in low intensity storms, and the cumulative evaporation was 67.7mm. At the end of this period, 20% of the total rainfall was accounted for by the measured increase in the profile water content of the bare NT soil, whereas there was no measured increase in the profile water content of the bare CT soil. Assuming that the net intake of rainfall was the same under the adjacent cropped areas, a significant correlation (r^2=0.8; n=5) was found between the actual measured water use, and the associated soybean dry matter yield increase during this period. These data show that the evaporative loss of water under a CT system, where the depth of water penetration is limited, is greater than that occurring within the NT system.

The result of long term NT has been an improvement in the stability and macroporosity of the surface soil and hence, a greater potential for the uptake and storage of water by the entire soil profile. In this way it is the structural improvement of the surface 10-15cm of the soil, through the use of long-term NT, which has led to the sustainable improvement of crop yields on these fragile soils.

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