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The impact of 14 years of conventional and no-till cultivation on the physical properties and crop yields of a loam soil at Grafton NSW, Australia

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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 weakly structured silty loam soil at Grafton in N.S.W. The annual soybean yields of the NT treatments between 1981 and 1985 were consistently less than or equal to those resulting from CT with an average of 2.46 t ha^{-1} and 2.82 t ha^{-1} respectively for the two treatments. However, CT was unable to sustain the greater yield, and from 1987 onwards the yields of the NT treatments have typically been greater than those of the CT with averages of 2.14 t ha^{-1} and 1.67 t ha^{-1} respectively.

During the earlier years of the trial, soil porosity and crop yields were not greatly affected by the different tillage techniques. During later years and at the end of the trial, however, soil porosity and structural stability were greater under NT. Increased soil macroporosity (Saturated water content of 0.61 for NT vs 0.40 for CT) and structural stability (Dispersed silt +clay contents of 10% for NT vs 30 % for CT) under long term no-till cultivation were consistent with higher saturated hydraulic conductivity (189 for NT vs 23 mm/h for CT), higher infiltration and lower run-off under rainfall, increased plant available water (12.5 % for NT vs 10.5 % for CT), water use efficiency, and crop yields. The improvement in soil structure observed under NT is associated with the significant increase in surface soil organic carbon contents (3.37 % for NT vs 1.67 % for CT) and is shown to be the major contributor to the sustained improvement of crop yields.

Keywords. Conventional tillage, no-till, bulk density, structural stability, infiltration, hardsetting soil.

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. So et al (2000) reviewed the effect of tillage and suggested that it might result in marginal increases in crop yield in the short term, however in the longer term it may be neutral or give rise to yield decreases associated with soil structural degradation. On marginal and degraded soils, tillage may be required to prepare suitable seedbeds or to release adequate nitrogen through mineralization, but in the longer term, tillage reduces soil organic matter content, increases soil erodibility and the emission of greenhouse gases. Loss of organic matter often results in increased bulk density of the surface soil because organic matter stabilize soil aggregates against slaking, dispersion and collapse. Repeated cultivation tends to give rise to subsoil compaction (Soane and Ouwerkerk, 1994; Kirchhof, 1995), largely as a result of traffic and associated loading.

As crop growth is fundamentally determined by the supply of water and nutrient, and this supply is in turn affected by the ability of the plants to grow an adequate root system to exploit them, tillage may have different effects on the production system in the short and long terms. The availability of water to crops and the development of the root system are greatly influenced by soil porosity. Hence, tillage may immediately increase the total porosity of soils (Hamblin, 1984; Lindstrom and Onstad, 1984) through the creation of a few irregular macropores (Pagliai et al, 1984). The increase in porosity and the consequent mineralization of N following cultivation may result in increased yield over a similar non-cultivated soil in the short term. However, prolonged continuous cultivation, such as the conventional tillage (CT) system, tends to reduce soil porosity through the mechanical breakdown of structure and compaction of the surface soil. 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.

In contrast, the prolonged use of continuous no-till (NT) has been shown to gradually improve the stability, macroporosity, and crop yields of loamy soils over time (Hamblin, 1984; Unger and Fulton, 1990). Within an 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) and Goss et al (1984) found a significant correlation between the increased macropore incidence and the greater earthworm population densities found in the soil under extended NT.

Many farmers on unstable, degraded or partially degraded soils associated with long term cultivation, faces the dilemma of whether to continue with the practice of repeated tillage (conventional tillage) for growing their crops, or to change to a reduced or no till system as a means of improving the health of their soil. A key question is whether the long term effect of possible increased yield outweighs the possible short term effect of yield reduction following the change to reduced tillage. The objective of this paper is to compare the effect of 14 years of conventional tillage and no-till on a fragile silty loam soil in the context of mechanized Australian agriculture.

Methodology

A field experiment was conducted at a site in Grafton, NSW, which has previously been under pasture for at least 5 years. The soil at the site had a weakly structured silt-loam A horizon (0-30 cm), which abruptly changed into a more strongly structured B horizon grading from clay loam to medium clay texture with depth. Such soils have been variously classified as red/yellow Podzolics (Stace at all, 1968), Kurosols (Isbell, 2002) or Ultisols (US Soil Survey staff, 1975). Under continuous cultivation, the surface tended to be hardsetting, (i.e. very hard when dry but soft when wet) with a restricted water holding capacity resulting in rapid changes from wet to dry in the surface soil. The site had a mean annual rainfall of 850 mm and evaporation of about 1000 mm (Linnacre and Hobbs, 1977). It had a uniform slope of 8 %.

The experiment began in 1981, and consisted of two tillage treatments (Conventional Tillage - CT and No-till - NT) within a crop rotation consisting of rainfed summer soybean (*Glycine max* (L.) cv Manta) and a winter cereal of oats (*Avena sativa*). Each treatment was replicated 3 times and each replicate consisted of a field plot measuring 60m x 20m. NT treatments were never disturbed other than during sowing operations, whereas CT treatments were chisel ploughed to a depth of 0.2 m and disk harrowed twice prior to planting each crop. Superphosphate was applied at a rate of 400kg.ha^{-1} four weeks prior to the sowing of the soybeans, and an additional 100kg.ha^{-1} was applied at sowing. Potasium fertiliser was applied in some years according to soil test requirements, at rates of up to 100kg.ha^{-1} K_2O. Molybdenum was applied as a seed dressing. A four row no-till planter was used on both treatments. Seedling counts were taken during the establishment phase of the soybean crop.

In 1995, undisturbed soil samples (76 mm diameter and 60 mm deep) were collected at 0.1 m intervals to a depth of 0.5 m to determine soil bulk density (McIntyre and Loveday, 1974). Soil structural stability was determined using the wet sieving technique (Kemper and Rosenau, 1986), and the percentage dispersible silt and clay by the end over end shaking technique (Cook et al, 1992). Soil water characteristics were determined on duplicate intact soil cores using the pressure plate technique (Klute, 1986). Soil strength measurements were made using a laboratory penetrometer on intact soil cores (Daquiado et al, 1998). Hydraulic conductivity were measured at field saturation and at -4 hPa tension using disc permeameters (Perroux and White,1988), Crop water use was monitored using a neutron moisture meter (Graecen, 1981). Yield was measured using 1m x 1m quadrat sampling with 3 replications per plot.

During the last soybean crop, areas of the field plot were intentionally cleared to measure infiltration of rainfall and its redistribution under prevailing field conditions. A rainfall simulator with an intensity of 80mm/hr was used to determine the infiltration and runoff characteristics of the bare soil using plots of 2 m x 1.5 m (Sheridan et al, 2000). The raindrop energy from the simulator is estimated at 29 J per mm of rain and is estimated as similar to the energy of natural rainfall. Undisturbed soil cores were collected before and after the simulation (McIntyre and Loveday, 1974), to examine the redistribution of infiltrated water. These cores were collected outside and adjacent to the plots which received the same rainfall intensity.

Results were analysed using the statistical package MINITAB.

Results and Discussion

Although some deeper measurements were made, significant treatment effects were detected only within the top 0.2 m of the soil profile. Previous work at the site by Harte and Desborough (1985) and Thompson (1986) found that soil bulk density (measurements confined to top 0.2 m) was not greatly affected by tillage during the early years of the trial. However, data from this work has shown that after 14 years, the NT surface soil has a significantly lower bulk density than the CT surface soil. (Fig 1a)

More importantly, Fig 1a shows that the bulk density of the CT surface soil did not change significantly over the 14 years of the experiment, whereas bulk density of the surface soil significantly decreased under NT. This indicates that a dominant effect was development of porosity under NT. The greater organic matter content of the NT surface soil (see Table 1) is consistent with this conclusion, as it is typically associated with greater biological activity (Graham and Haynes, 2006). Soil bulk density below a depth of 0.2 m was similar under CT and NT.

The smaller values of dispersible silt and clay (Fig 1b), together with the greater mean weight diameter (Fig 1c) indicate that the NT surface layers were more stable and better aggregated than the CT soil. These differences in stability are consistent with those in soil organic matter content for the different treatments. The collapse of larger unstable aggregates, and the associated increase in the smaller aggregate sizes (Figure 1b and 2) is likely to contribute to the lower porosity and greater bulk density of the CT surface soil.

The NT surface soil had a greater hydraulic conductivity at field saturation (K_{sat}) and a smaller unsaturated hydraulic conductivity (K_{unsat}) than the CT surface soil. At – 4 hPa suction, all pores greater than 0.75 mm are drained, hence the difference between K_{sat} and K_{unsat} (at -4 hPa matric potential) is due to the contribution of macropores with a diameter >0.75 mm known as the transmission pores. 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 affected by tillage (Table 2). As expected, the soil water content at wilting point (Ψ_M = -1.5 MPa) was similar for the two treatments. However, at field capacity (Ψ_M = -0.01 MPa) and at saturation (Ψ_M = 0 MPa), water content is strongly affected by soil structure and in the top 10 cm of the NT soil, it was greater than for CT, leading to 22% more plant available water. This in turn may well have improved establishment.

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 0 MPa and -0.01MPa, and also between -0.01 MPa and -1.5 MPa. This is consistent with the greater 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 should be superior to that of the CT profile.

Soil strengths above 2000kPa are thought to impede root extension and 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 2000 kPa (Table 3). The combination of reduced plant available water holding capacity and greater soil strength suggests that the ability of roots to explore the soil may have been inhibited to a significantly greater extent under CT. In the absence of root sampling, this remains speculative. No significant differences in soil strength were detected between the treatments at matric potentials of 0 MPa (saturation) or -0.01 MPa (field capacity). Differences at matric potential of – 1.5 MPa is associated with the lower soil bulk densities under NT compared to CT (Fig 1).

Under simulated rainfall, the steady state infiltration rates of CT plots were significantly slower than those of NT plots (5 mmh^{-1} and 25 mmh^{-1} respectively). These infiltration rates were consistent with the soil water content profile data, which found that after the simulation, total water contents of the NT and CT soil profiles had increased by 27 mm and 13 mm respectively. A reduction in infiltration typically results in greater runoff and soil loss and the calculated soil losses during the rainfall simulation were equivalent to 12.1 t ha^{-1} and 2.6 t ha^{-1} under CT and NT respectively. These infiltration rates were much lower than the rates measured with the disc permeameter (Table 1) which indicates the susceptibility of the aggregates of these fragile silty loam soils to degradation from raindrop impact.

Immediately prior to rainfall simulation, the initial soil profile water contents of the two treatments were similar and could be plotted as a single line (Figure 3). Immediately after simulation, significant changes to water content occurred at depths of 0.25 m and 0.075 m for the NT and CT treatments respectively. Two days later infiltrated water had moved further into the profiles of both treatments. These observations are consistent with anecdotal reports that very little run-off from the NT fields relative to CT fields following intensive rainstorms is typical of the coastal regions of Australia.

Surface sealing was observed on CT soil under rapid wetting from rainfall. 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 consistent with the greater strength of the CT surface soil when dry.

The relationship between crop yields and tillage practices has changed over time. The annual soybean yields of the NT treatments between 1981 and 1985 were consistently less than or equal to those resulting from CT (Figure 4) and average 2.46 t ha^{-1} and 2.82 t ha^{-1} respectively for the two treatments. CT was unable to sustain the greater yield, and from 1987 onwards the yields of the NT treatments have typically been greater than those of the CT (averages of 2.14 t ha^{-1} and 1.67 t ha^{-1} respectively).

Insert Fig 4 here

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 the measurement period or cropping season, plus the rainfall during that period) and crop yield were examined. The dry matter yield, grain yield and the associated apparent water use efficiencies (WUE) of the winter oat crop were all greater under NT (Table 4). It is most likely that greater evaporative losses from the soil in CT results in lower DM WUE than in NT associated with the lower saturated and higher unsaturated hydraulic conductivities in CT (Table 1). A reduced harvest index in plants grown on CT soils resulted in greater reduction in grain WUE compared to plants grown on NT. The reasons are not clear, however observations show significantly poorer growth on CT, most likely due to reduced root development associated with greater soil strength in the CT soils (Table 3). Under dry temperate climatic conditions, Goss et al (1978) found similar results with winter wheat where water uptake was significantly higher where wheat was grown under no tillage systems compared to conventional cultivation. However in the wetter years, no differences were observed between the two cultivation methods. Similar results were obtained from dry matter sampling during the following soybean crop, however, limited rainfall and extensive pest damage during the growth of that crop confounded the final yield data for both treatments and could not be used. 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. 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 68.9 mm of rain fell at the experimental site in low intensity storms, and the cumulative evaporation was 67.7 mm. 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, which reduced the apparent total water use. There was no measured increase in the profile water content of the bare CT soil.

Conclusions

1. The early years following the introduction of no till cultivation on an unstable degraded silty loam soil will result in a small depression of crop yields, thereafter no till consistently performs better than conventional cultivation.
2. The result of long term no till cultivation has been an improvement in the aggregate stability and macroporosity of the surface soil and hence, a greater potential for infiltration and storage of water by the entire soil profile. Therefore, the structural improvement of the surface 10-15 cm of the soil, through the use of long-term practice of no till cultivation, led to the sustainable improvement of crop yields on these fragile soil.

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References

Burch, G.W., Mason, I.B., Fischer, A.B., Moore, I.D., 1986. Tillage effects on soils: physical and hydraulic responses to direct drilling at Lockhart, New South Wales. Aust. J. Soil. Research. 24, 377-391

Chan, K.Y. , Heenan, D.P., 1993. Surface hydraulic properties of a red earth under continuous cropping with different management practices. Aust. J. Soil Res. 31, 13-34.

Chan, K.Y. , Mead, J.A., 1988. Surface properties of a sandy loam soil under different tillage practices. Aust. J. Soil Res. 26, 549-559.

Cook, G.D., So, H.B., Dalal, R.C., 1992.. Structural degradation of Vertisols associated under continuous cultivation in Southern Queensland, Australia. Soil and Tillage Research 24: 47 - 64.

.Daquiado, N.P., 1998.. Assessing the limitations on soil productivity imposed by hardsetting properties. Ph D Thesis, University of Queensland, Australia.221 p

Goss, M.J., Howse, K.R., Harris, W., 1978.. Effects of cultivation on soil water retention and water use by cereals in clay soils. Journal of Soil Science 29: 475-488.

Graecen, E.L. (1981). Soil water assessment by the neutron method. C.S.I.R.O., Australia.

Graham, M.H., Haynes, R.J., 2006. Organic matter status and the size, activity and metabolic diversity of the soil microbial community in the row and inter-row of sugarcane under burning and trash retention. Soil Biology & Biochemistry 38: 21-31.

Hamblin, A.P., 1984. The effect of tillage on soil surface properties and the water balance of a xeralficalfisol. Soil and Tillage Research. 4, 543-559.

Harte, A.J., Desborough, P.J., 1985. Internal Report, NSW Soil Conservation Service

Isbell, R.F, 2002. The Australian Soil Classification. CSIRO Pub., Collingwood, VIC, Australia , 144 pp

Kemper, W.D. and Rosenau, R.C. (1986). Aggregate stability and size distribution. In A. Klute (Ed) Methods of soil analysis, part 1. American Society of Agronomy Monograph no 9, p 425-42.

Kirchhof, G., 1993.. Compaction properties of vertisols and their potential effect on sunflower. PhD thesis, University of Queensland, St Lucia, Qld, Australia.

Klute, A (1986). Water retention: Laboratory methods. In A. Klute (Ed), Methods of soil analysis, part 1. American Society of Agronomy Monograph no 9, p 635-62.

Lal, R., Logan,T.J., Fausey, N.R., 1989. Long term tillage and wheel traffic effects on a poorly drained mollic ochraqualf in northwest Ohio. 1. Soil physical properties, root distribution, and grain yield of corn and soybean. Soil & Tillage Research 14, 341-358.

Linacre, E., Hobbs, J., 1977.. The Australian Climatic Environment. John Wiley & Sons, Brisbane.

Lindstrom, M.J., Onstad,C.A., 1984. Influence of tillage systems on soil physical parameters and infiltration after planting. J. Soil & Water Consv. March-April 1984, 149-152

McIntyre, D.S. and Loveday, J. (1974) Bulk Density. In J. Loveday (Ed) Methods for analysis of irrigated soils. Tech. Comm. No 54, Comm. Bureau of Soils, Comm. Agric. Bureau, Farnham Royal, England, p 38-42.

Pagliai, M., La Marca, M., Lucamante, G., Genovese, L., 1984. Effects of zero and conventional tillage on the length and irregularity of elongated pores in a clay loam soil under viticulture. Soil & Tillage Research. 4, 433-444.

Perroux, K.M., and White, I., 1988. Designs for disc permeameters. Soil Science Society of America Journal 53, 324-329

Sheridan, G.J., So, H.B., Loch, R.J., Pocknee, C., Walker, C.M., 2000. Use of laboratory-scale rill and interrill erodibility measurements for the prediction of hillslope scale erosion on rehabilitated coal mine soils and spoils. Special issue: Australian Journal of Soil Research 38, 285 - 297.

So, H.B., Kirchhof, G., Bakker, R., Smith, G.D., 2000. Low input tillage/cropping systems for limited resource areas. In Morrison, JE(Ed).ISTRO 2000: Proc. International Conference of the International Soil Tillage Research Organisation. CD-ROM, USDA-ARS, Temple, Texas, USA

Soane, B.D., van Ouwerkerk, C., 1994.. Soil Compaction in crop production. Developments in agricultural engineering. Elsevier Science, Amsterdam.

Soil Survey Staff, 1975. Soil taxonomy : a basic system of soil classification for making and interpreting soil surveys. Handbk. US Dept. Agric.

Stace, H., Hubble, G., Brewer, R., Northcote, K.,Sleeman, J., Mulcahy, M., Hallsworth, E., 1968. A handbook of Australian soils. Relim Tech. Publ.: Glenside, South Australia.

Thompson, D., 1986.. Soil structure investigations in conservation tillage for crop and pasture production on the north coast of NSW. In Cole, BE, Desborough, PJ (eds) Project team meeting, Grafton, NSW, August 1986.

Unger, P.W., Fulton, L.J., 1990. Conventional and no-tillage effects on upper root zone soil conditions. Soil and Tillage Research, 16, 337-344.

Table 1 : Soil physical properties after 14 years of cropping. Organic matter data after Daquido (1998)

Physical Property of the Soil		No-Tillage	Conv Tillage	l.s.d.	Prob %
Percentage organic matter		3.37	1.65	na	
Hydraulic conductivity	saturated	189.4	28.0	75.5	0.01
of surface soil (mm/h)	unsat(- 4 hPa)	2.3	10.8	7.8	0.05

Table 2: Water contents (m^3/m^3) at different potentials, for CT and NT soils 14 years after commencement of the trial. Superscripts indicates significant differences at P<0.05 within each depth interval.

MATRIC POTENTIAL (MPA)	DEPTH					
	0 – 50 mm		50 – 100 mm		100 – 200 mm	
	CT	NT	CT	NT	CT	NT
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}
	Differences in water contents					
0 – 0.01 (drainable pores)	6.5	12.5	5.0	4.0	11.0	9.0
0.01 – 1.5 (available water)	10.5	12.5	8.0	10.0	18.0	17.0

Table 3: Soil strength (kPa) under CT and NT at a matric potential of –1.5 MPa after 14 years of treatments. Superscripts indicates significant differences at P<0.05 within each depth interval.

Depth	CT	NT	Average
0 – 5 cm	1874[a]	1236[b]	1555
5 – 10 cm	2898[a]	1927[b]	2413'
10 – 20 cm	3709[a]	2234[b]	2972
Average	2827	1799'	

Table 4: Crop water use and yield data for the oats and soybean crops. N/A not available.

Crop & treatment	Dry matter @ 80 days (t/ha)	Total 80 days water Use (mm)	DM Water Use Efficiency (kg /ha/mm)	Grain Yield (kg/ha)	Total seasonal water use (mm)	Grain Water Use Efficiency (kg/ha/mm)
Oats NT	5.72	97.2	58.8	661	127.1	5.2
Oats CT	4.45	97.1	45.8	290	131.8	2.2
Soy NT	2.61	121.7	21.4	N/A	N/A	N/A
Soy CT	1.74	125.3	13.9	N/A	N/A	N/A

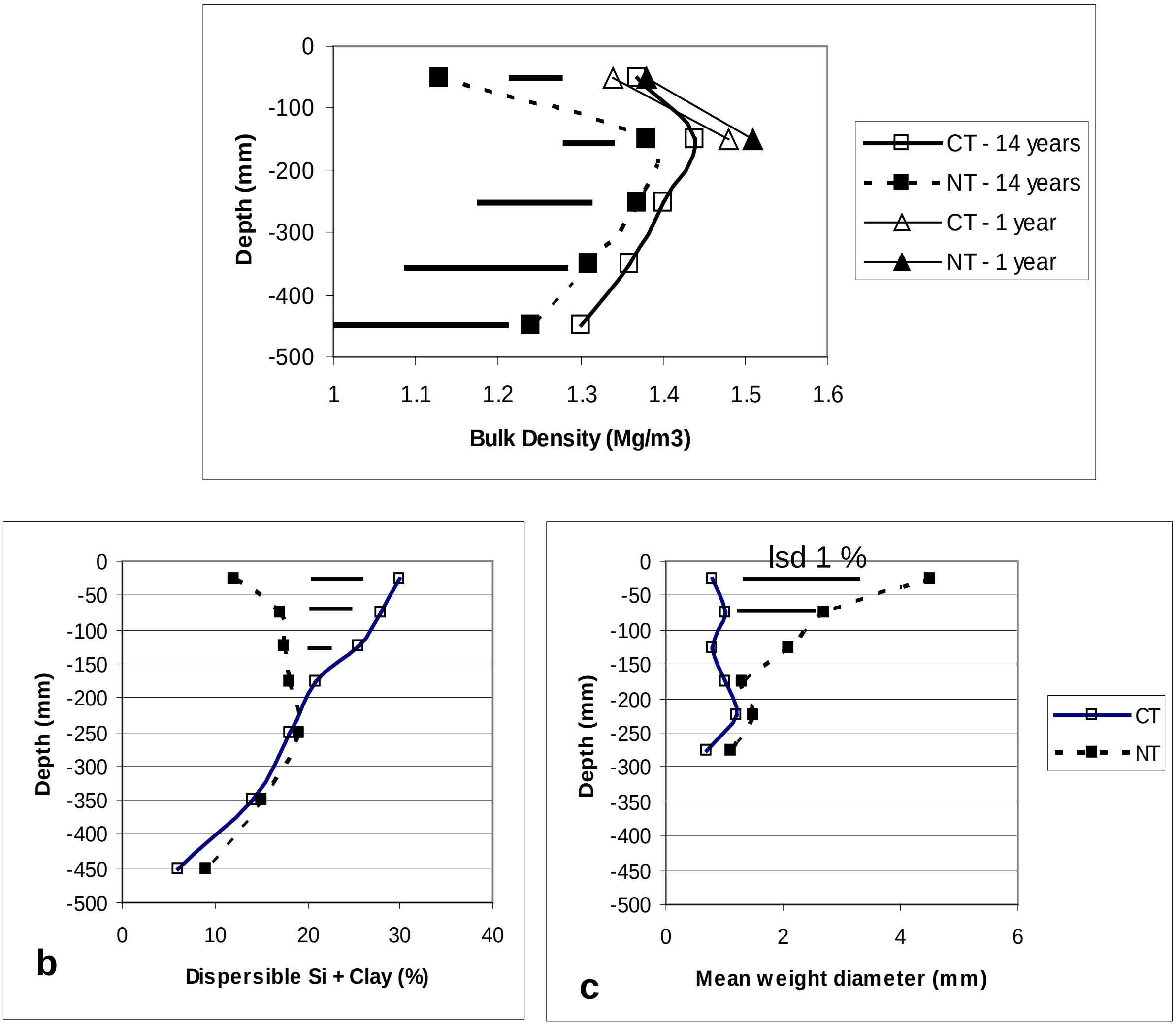
Figure captions

Figure 1: The effect of cultivation on the bulk density (a), Dispersible silt + clay (b) and mean weight diameter (c) as a function of depth. Bars indicate LSD at 5 % unless indicated otherwise. The first year bulk density is taken from data of D.Thompson (1986)

Figure 2: Proportion of total aggregates in each size class. Bars indicate Lsd at 5 %

Figure 3: Initial distribution of water in the profile before the application of simulated rainfall of 40 mm, immediately and 2 days after simulation.

Figure 4: Soyabean yield during the 14 years of trial history. * significant at 5 %, **highly significant at 1 %.



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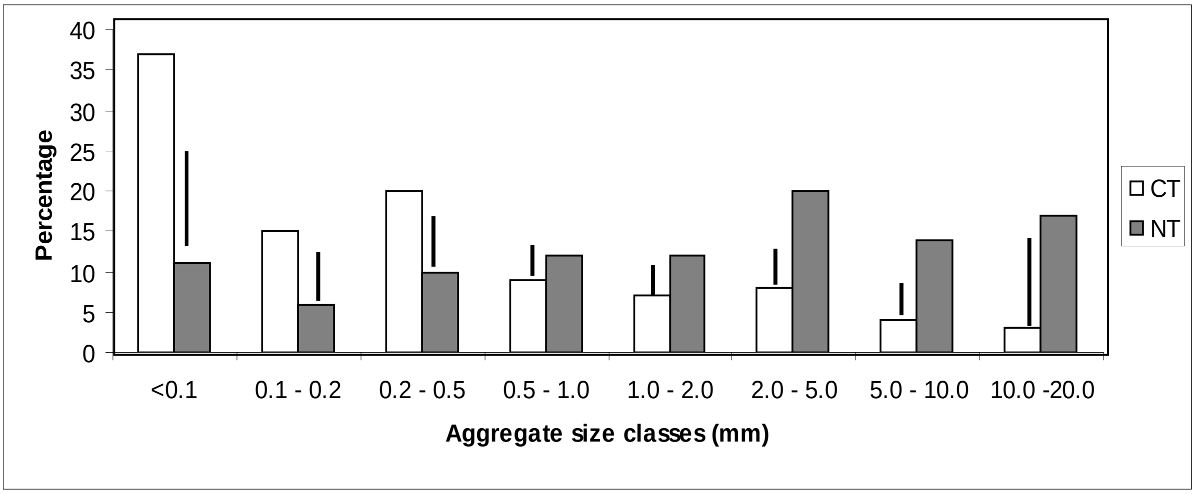
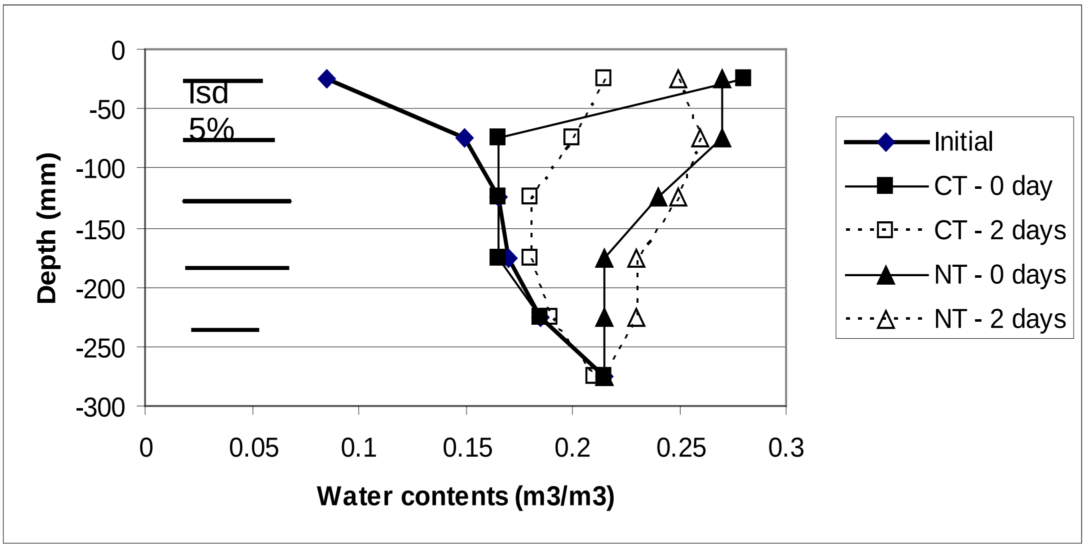


Figure 2: Proportion of total aggregates in each size class. Bars indicate Lsd at 5 %



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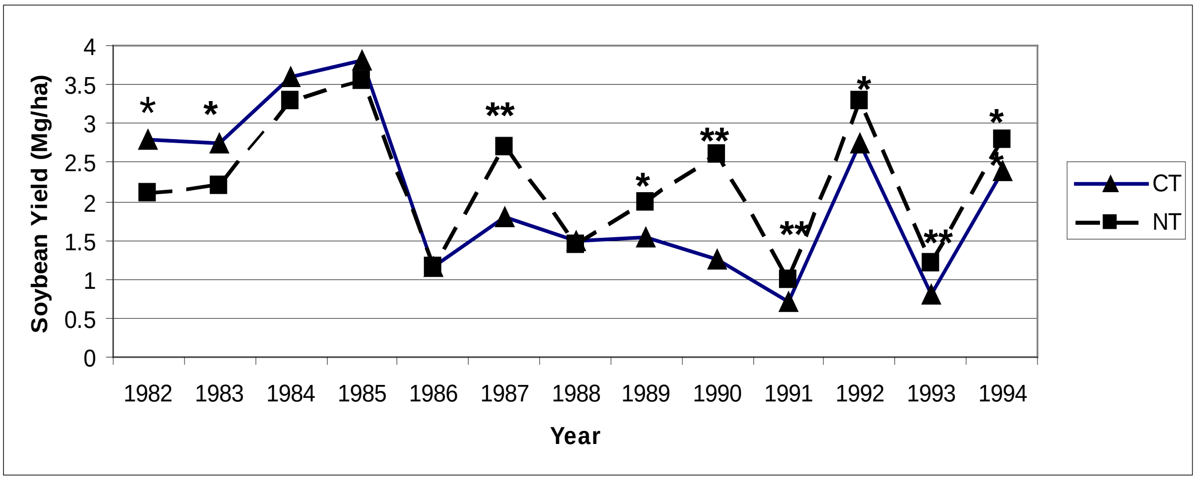

Figure 4: **Soyabean yield during the 14 years of trial history. * significant at 5 %, **highly significant at 1 %.**