Six Years of Controlled Traffic Cropping Research on a Red Brown Earth at Roseworthy in South Australia.

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Introduction:

The sustainability of agricultural production is linked closely to surface and subsoil management. Both tillage and heavy wheel traffic cause a decline in soil structure. This is an unintended consequence of conventional agricultural practices using tillage and associated machine wheel traffic. The intensity, type of loading and soil moisture during compaction can affect tillage conditions and produce a hardpan layer below the cultivation depth. Compaction damage can be reduced by using lighter or lower ground pressure implements, or by using controlled traffic (CT) cropping systems which eliminate wheel traffic from the cropped zones by confining wheel positions to permanent wheel tracks. The future trend in weight of agricultural machinery is unlikely to result in lighter tractors and implements, in fact studies have shown that soil has sometimes to bear axle loads which would be banned on public highways (Spoor, 1988). Therefore one of the most suitable methods of approaching this technologically created compaction dilemma is application of Controlled Traffic Systems and use of gantries or the like.

Background to Controlled Traffic Project at Roseworthy:

The research on controlled traffic cropping at Roseworthy started in 1989 and thereafter was funded by the Grains Research and Development Corporation (GRDC) until the end of June 1995.

1. Project Aims:

- to examine the usefulness of controlled wheel traffic, as a practical method of preventing soil compaction, in increasing yield of cereals and grain legumes as well as its effectiveness in improving plant and soil properties.
- to investigate the benefits of the higher rates of water entry observed in controlled traffic treatments.
- to determine the influence of controlled traffic on beneficial and detrimental soil fungi.
- to investigate the effect of controlled traffic on medic pasture.
- to gain a better understanding of the causes of consistently higher yields and root densities measured on crops grown in the absence of wheel traffic.
- to develop approaches to validation and utilisation of this technology on farms.
- to demonstrate that controlled traffic is an important element of sustainable cropping systems.

2. Machinery and Experimental Treatments:

All operations on Controlled Traffic trials were conducted with a John Shearer self propelled prototype gantry using tillage, seeding and spraying implements modified to be carried by the gantry. This provided 4.4 m wide experimental plots with 4 m cropping beds which were not wheeled at all. For cultivating and sowing purposes a John Shearer 6-90 Trash-culti-drill, fitted with direct drill tynes, was modified to be suspended under the gantry. A 5m wide spray rig was also modified and mounted on a frame especially designed to be suspended under the gantry for spraying purposes. For harvesting purposes a Massey-Ferguson 585 header was modified, matching the gantry wheel spacing to enable harvesting the plots from permanent tracks. Prickle chains were also pulled behind the gantry for harrowing purposes. To maintain wheel tracks free from weeds, scrapers which were hydraulically controlled from the gantry, were mounted behind the wheels of the gantry.

A Conventional (C) cropping system was included for comparison. Conventional wheel traffic was applied during tillage, seeding and spraying operations using tractors and trailed implements. For cultivating and sowing purposes the same 6-90 Trash-culti-drill was pulled behind the tractor.

Deep ripped treatments of both C and CT were also carried out in the field to investigate the effects of subsoiling and disturbance of a hardpan on crop yield and other related plant and soil properties. Deep ripping to a depth of 300 mm was done in Autumn 1989 prior to start of the experiment with a John Shearer Trashworker chisel plough with tynes at 30 cm spacings and fitted with 50 mm points.

Experimental Treatments and Experimental Design:

C	Conventional wheel traffic Using tractor and trailed implements	**CR**	C, deep ripped to 300 mm prior to trial
CT	Controlled traffic using prototype gantry	**CTR**	CT, deep ripped to 300 mm prior to trial

These were replicated four times in a split plot design. The main treatments were"ripping" and "no ripping" and the sub treatments were "traffic" and "no traffic" (Ellis et al, 1992). The last three years of the project were concentrated on no ripped CT and C treatments only. In this case C and CT formed a Randomised Complete Block Design experiment.

The site occupied about 4 ha and the C and CT plots were 6 and 4 meter wide respectively. All plots were 275 meter long. Five meter wide borders separated all main plots to allow vehicle access. The size of each replicated plot was 0.1 ha. Each treatment was also represented by 2.5 ha management plots in the northern and southern side of the experimental site to address management issues such as weed control on permanent wheel tracks, stubble management, guidance of machinery and depth control of tillage and seeding implements. The northern management site was later on utilised for water-use efficiency studies.

Soil loss to wheel tracks and use of narrower tyres:
Permanent wheel tracks at Roseworthy were not sown to crop, for visibility and better manoeuvrability of the machinery, and represented 16% of the total area lost in permanent tracks in 1989 and 10% thereafter following the fitting of narrower tyres to the gantry. The benefits of the controlled traffic system were more than enough to compensate for the lost area of land to wheel tracks.

Cropping Sequence:
The cropping sequence was barley (*Hordeum vulgare* cv Galleon) in 1989, faba bean (*Vicia faba* cv Fiord) in 1990, wheat (*Triticum aestivum* cv Spear) in 1991, faba bean (cv Fiord) in 1992, wheat (cv Machete) in 1993 and medic pasture (*Medicago truncatula* cv Paraggio) in 1994.

Crop and Pasture Measurements:
seedling establishment, phenological development, crop biomass, grain yield, grain protein, effective rooting depth, root density and root diameter, root morphology, nitrate analysis in medic pasture.

Soil Measurements:
Bulk density, penetrometer resistance, soil hydrology - permeability, infiltration patterns, runoff, drainage, sorptivity, water extraction pattern, water stable aggregates (WSA) - recovery of soil aggregates from compaction, soil porosity and biopores and soil biological activity (earthworm numbers).

Extension:
Dissemination of results occurred through student seminars (Roseworthy Campus ,Waite Campus ,CSIRO), publications in state and national workshop proceedings (CRC for Soil and Land Management, annual tillage workshop), conference proceedings (National Soil Conference, Agricultural Engineering Conferences, etc), national journals, articles in stock journals and Kondinin magazines, radio talks, attending Paskeville, Hart and AGTEXPO (a joint field day run in conjunction with SARDI, CRC for Soil and Land Management and the University of SA) field days, presentation to visiting farmer groups and attending farmers' discussion nights. Given that there are existing commercialisation limitations to the extension of gantry-based controlled traffic and considerable cost involved in the adoption of the system by farmers, a part of the research has concentrated on axle modification of existing tractors and harvesters which can enable the on-farm application of a controlled traffic system at low cost.

Results and Discussion:

1. Crop Yield:

The harvest times for all crops were in late November/December. In all years the centre of the C and CR plots were harvested, leaving a 0.5 meter strip both sides to exclude any plot edge effect from the sample. The entire width of the CT plots was harvested because any edge effect caused by the permanent wheel tracks was considered to be normal for a controlled traffic system and not an artefact of the plot geometry. Yield transects transverse to the rows, were done by cutting 0.25 m^2 quadrats in 1990 and 1 meter length of row in 1991. Grain yields were calculated from the number of grains in each sample combined with 100 grain weight. The contribution of the edge effect to the final yield of the plot was about plus one percent. Crop yield in 1992 when the trial was under faba bean was estimated by finding the weight of 1000 beans. 1992 was a wet year (twice average annual rainfall) and this made harvest impossible because of severe weed infestation of the plots. The grain yield for 1993 was obtained by machine harvesting. In 1994 treatments were sown to annual medic pasture and its growth in a controlled traffic system was studied (Sedaghatpour et al, 1995). Samples for medic seed production were taken using a suction harvester in January 1995.

Positive yield responses were produced by controlled traffic treatments over 6 consecutive years. Data showed average yield increases of 12% in cereal and grain legumes and about 22% in parragio medic. Yield parameters like herbage biomass, nitrogen uptake, single grain weight, weight of thousand seeds, number of heads, and number of grains per head contributed to these increases in yield. Table 1 shows crop and medic pasture yield for each treatment. In all years there was a statistically significant ($p < 0.05$) interaction between main treatments.

Table 1: Effect of Wheel Traffic, Deep Ripping and their interaction on crop yield

Year of Experiment	Avg Yield C kg/ha	Avg Yield CT kg/ha	Diff. in yield (C & CT) kg/ha	Avg Yield CR kg/ha	Avg Yield CTR kg/ha	Diff. in yield (CR &CTR) kg/ha	LSD (0.05)	LSD (0.05)*	Avg yield C & CR (Wheel)** kg/ha	Avg yield CT & CTR (No Wheel)** kg/ha	Diff. in yield kg/ha	LSD (0.05)	Avg yield C & CT (No Ripping) kg/ha ***	Avg yield CR & CTR (Ripping) kg/ha***	Diff. in yield kg/ha	LSD (0.05)
1989 (Barley)	3130	3330	200	3140	3540	400	162.2	181.3	3135	3435	300	128.2	3230	3340	110	128.9
1990 (Bean)	1985	2327	342	2046	2121	75	101.8	114.3	2015	2224	209	80.7	2156	2083	73	80.2
1991 (Wheat)	2562	2872	310	2740	2775	35	108.2	86.9	2561	2824	263	61.4	2717	2757	40	115.5
1992 (Bean)	3964	4519	555	5538	3387	2151	1316.0	889.5	4751	3953	798	629.1	4751	3953	798	1503.4
1993 (Wheat)	3046	3157	111	3155	3320	165	400.8	377.8	3100	3238	138	267.2	3100	3238	138	388.6
1994 (Medic)	361.8	447.3	85.5	349.2	398.2	49	26.7	26.4	356	423	67	18.6	405	374	31	24.8

* Use this column when comparing average yields with the same level of traffic or ripping.

** This table compares the effect of wheel traffic on crop yield (group effect without reference to ripping). **Results are significantly different in absence of wheel traffic**

*** This table compares the effect of ripping on crop yield (group effect without reference to wheel traffic). **There is not significantly different result between ripped and non-ripped treatments.**

Note: | difference in yield | > LDS(0.05)⇒significantly different result

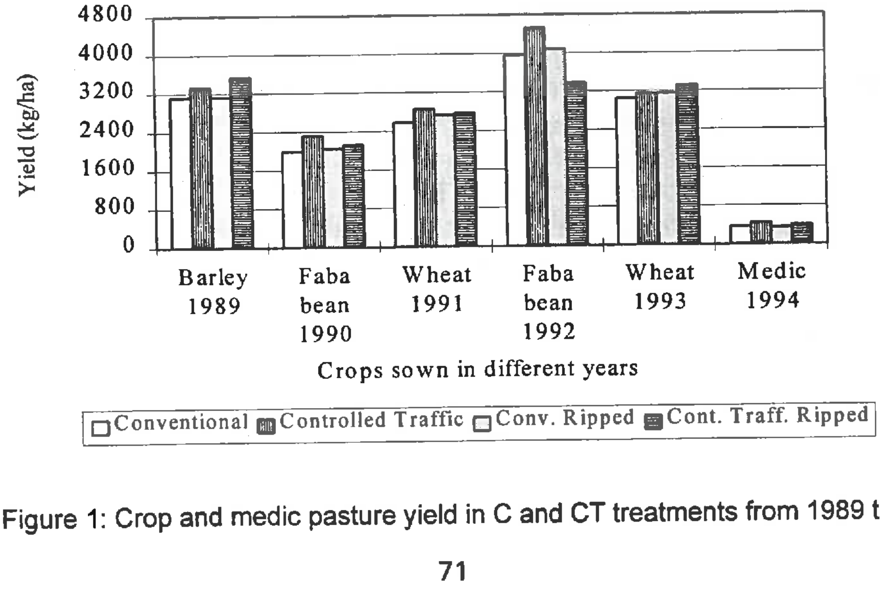

Figure 1: Crop and medic pasture yield in C and CT treatments from 1989 to 1994

2. Plant Root Characteristics:

Root densities of wheat(1991, 93), faba beans (1992) and medic pasture (1994) were studied. The results were consistent and were significantly different in CT comparing to C. Fig 2 shows the rooting behaviour of wheat in 1991, medic pasture in 1994, and root morphology of faba bean in 1992. Because of possible effect of water uptake on grain filling and yield, the effect of wheel traffic on rooting density and length was investigated.

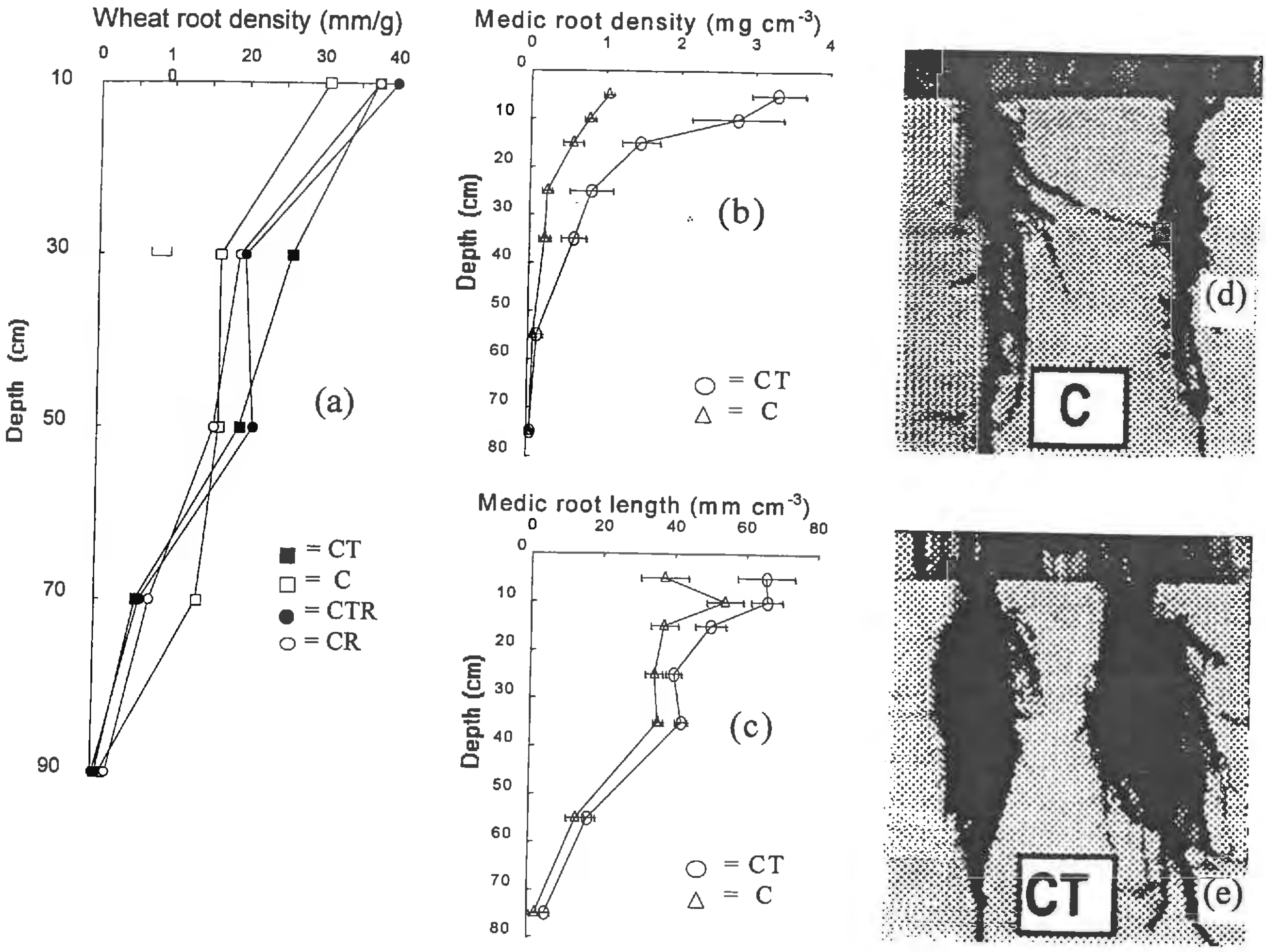

Figure 2: (a) wheat root density at anthesis in 1991. The bar represents significant differences at the 30 cm depth. (b) and (c), medic pasture root density and root length. (d) and (e) morphological study of roots of faba bean seedlings to 15 cm soil depth in 1992. Better root establishment and development and more lateral roots were observed in CT than in C.

3. Soil Strength:

Soil penetration resistance using a cone penetrometer was measured in each year. Fig 3 shows soil resistance to penetration by a cone penetrometer after 5 years of controlled traffic. Large differences in penetration resistance at soil depth (70-100 mm) between C and CT shows that zero traffic had ameliorated the soil hardpan. It is important to note that this occurred *naturally*, presumably due to the action of plant roots, soil fauna, wetting and drying cycles when there was no compaction because of wheel traffic on cropped zones.

4. Soil Bulk Density and Soil Porosity:

Bulk density increases when soil is compacted. The degree of compaction depends on soil water content at the time of compaction (Weaver and Jamison 1951) and a small increase in bulk density can cause a large increase in penetration resistance (Voohees et al, 1978) and decrease in size of large pores. There is a trend towards lower bulk density in both surface and hardpan zones under CT (Fig 4). Bulk density was consistently lower in CT in 1991 through to 1994 and supports the results of penetrometer experiments (Fig 3) which were done simultaneously. Soil porosity in CT was greater than in C (Fig 6) in top 100 mm of soil depth.

5. Soil Aggregate Stability:

Aggregate stability is an important indicator of the sustainability of agricultural practices. It has significant role in relation to wind and water erosion (Wischmeier et al, 1969), plant growth (Passioura, 1991) and yield.

Both tillage operation and wheel traffic causes a decline in soil structure as measured by soil aggregate stability. The results of early years were not significantly different and after 5 years of continous controlled traffic practices the differences between C and CT treatments started to show up. Fig 5 shows the effect of rain on Water Stable Aggregates (WSA). Cumulative percentage of aggregate sizes are significantly different in CT treatment in 1993-94 comparing with results from 1991-92 in which years treatments were sown to wheat.

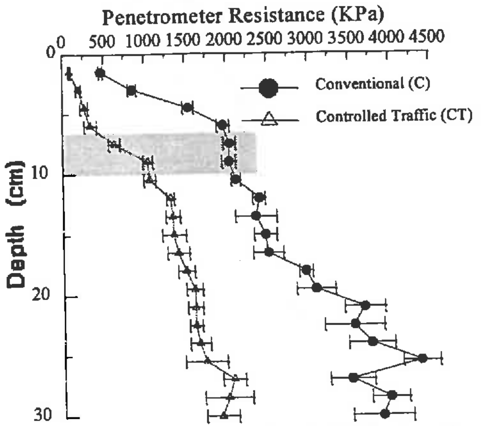

Figure 3: Core penetrometer profile in 1993 when the experiment was sown to wheat.

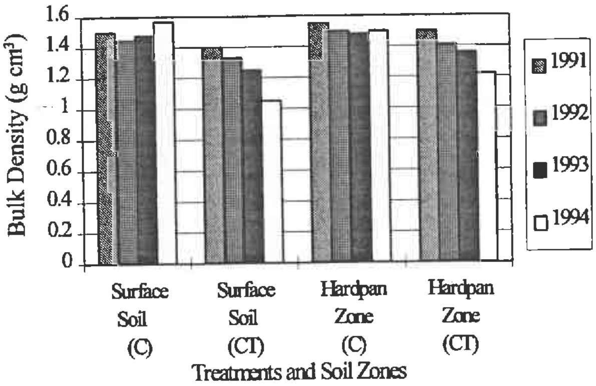

Figure 4: Soil Bulk Density from 1991 to 1994 in surface (0-50 mm) and hardpan (50-100 mm) zones. Results support penetrometer experiments.

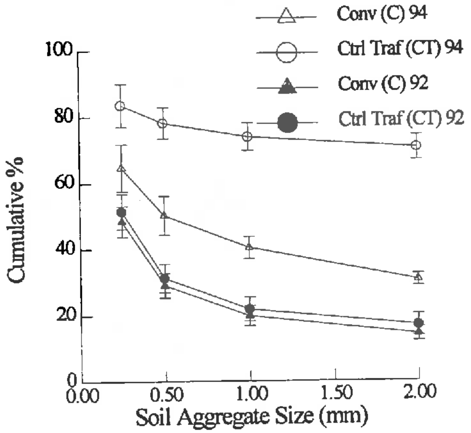

Figure 5: Surface soil aggregate stability in C and CT.

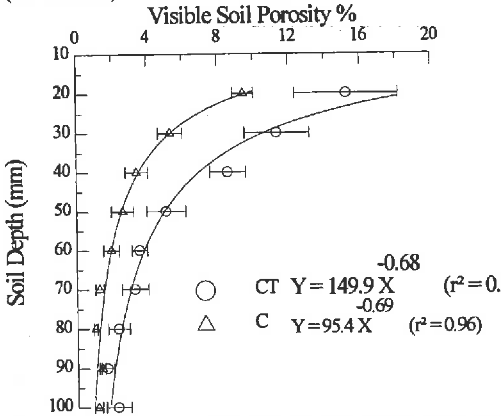

Figure 6: Soil porosity in top 100 mm of soil depth, in C and CT treatments.

6. Hydrological Characteristics of Soil:

6.a) Sorptivity as an index to assess the effect of wheel traffic on soil:

Sorptivity depends on the very early stages of infiltration of water into the soil (Philip, 1957). The hydraulic characteristics of the soil, particularly the top few millimetres, are critical (Sauer, et al, 1989) and related to presence of macropores. Wheel traffic can affect surface soil pore geometry and destroy, or block macropores to water entry. Sorptivity has been used as an index to assess the effect of wheel traffic on soil (Sedaghatpour and Ellis, 1994). Fig 7 shows that the value of sorptivity for CT is almost double of the value for C and sorptivity proved to be higher on CT in the last two years of controlled traffic when experiments were fully established.

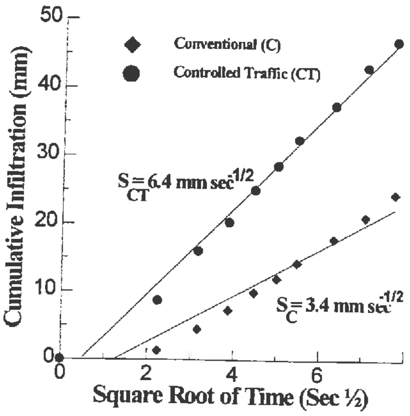

Figure 7: Sorptivity in C and CT. Lines fitted to the linear part of infiltration data to calculate sorptivity.

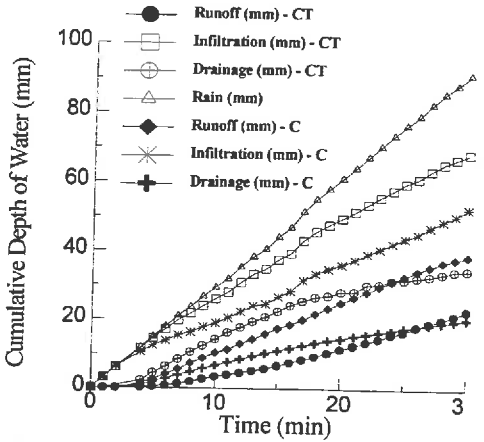

Figure 8: Rainfall Characteristic Curves for Conventional and Controlled Traffic treatments (wheat crop).

6.b) Rain, Infiltration, Runoff, and Drainage:

Other hydrological behaviour of soil under CT and C was studied (Sedaghatpour, et al, 1993, 1994), a month after harvest when sheep finished grazing, using an indoor rainfall simulator. Fig 8 shows significantly different results ($p<0.05$), in favour of CT comparing with C, for water infiltration, runoff and drainage under a rainfall energy of 8 $Jm^{-2}mm^{-1}$. The differences between treatments were observed 10 minutes after simulated rainfall commenced. The higher rate of water entry into CT soil could be because of its lower bulk density and higher porosity than C.

Discussion:

After 6 years of CT at Roseworthy, controlled traffic resulted in higher grain yields of wheat, barley and faba bean crops and higher herbage and seed production from medic pasture, compared to conventional (C) farming systems. This plant growth advantage was associated with improvement in a range of soil parameters including; bulk density, penetration resistance, soil porosity, increased sorptivity and water infiltration into the soil profile, higher cumulative percentage of water stable aggregates (WSA), longer and more lateral roots, higher rooting density, greater above ground plant production, better development of other components associated with yield, higher biological activities in soil (earthworm numbers - twice number in CT than in C, Sedaghatpour and Ellis, 1994) as well as greater effectiveness of direct drilling. These changes appear to be principally a result of the action of roots, macro fauna and wetting and drying cycles and have led to improvements in soil condition and crop yields. It was found that exclusion of wheel traffic without deep ripping can allow natural processes for improving soil structure. Such a method has the potential to be more cost effective and long lasting than mechanical or chemical methods of soil amelioration.

The effect of soil compaction on crop growth and yield can depend on the amount and temporal distribution of rainfall throughout the growing season (Boone 1988). A dense soil may give a yield advantage over a less dense soil in a "dry" year but the less dense soil may give a higher yield in a "wet" year (McKyes et al. 1979). Generally though, soil compaction by wheel traffic has a determinal affect on crop yield (Hakansson, 1987). Decrease in crop yield brings up the economic consequences to which ecological consequences could be added (Lhotsky, et al. 1991). Therefore, soil compaction is an urgent problem and a **practical preventive method** should be sought and used in fields.

Acknowledgments:

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