Contrasting soil physical properties after zero and traditional tillage of an alluvial soil in the semi-arid subtropics

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Abstract

Zero till is commonly advocated as a preferred cropping system to conventional, multicultivation practices. Zero till is particularly attractive on clay soils, to minimise compaction and induce natural structure formation through shrink–swell cycles. Increases in soil water storage and increased numbers of (beneficial) soil fauna with zero till have been reported, relative to traditional tillage. This work identifies reasons for improved soil and crop responses under zero till on an alluvial Vertisol from Biloela, Qld. All measurements were taken after 8 years of the trial. By then, the traditional till treatment (TT) had received 34 tillage operations while zero tillage (ZT) had received none. Data collected were sorptivity and hydraulic conductivity of the soil surface at four tensions as measured by disc permeameters, water infiltration with a rainfall simulator, and image analysis of soil structure from Araldite-impregnated intact soil blocks. Chloride concentrations to a depth of 4.5 m were also measured. The sorptivity and hydraulic conductivity data demonstrated that ZT had the greater volume of the largest pore size measured (1.5–3 mm), whereas TT had the greater volume of pores <1.5 mm diameter. Rainfall simulation at 100 mm h⁻¹ showed that the time to ponding, final infiltration rate and the total infiltration were all significantly greater in ZT than TT. From the image analysis it was evident that ZT had an abundance of apparently continuous soil pores from the soil surface to depth that appeared round in cross section. In contrast, TT had a high-density surface crust and significantly larger soil structure units than ZT from 0.15 m. The image analysis results corresponded well with the high counts of earthworms and termites previously recorded in ZT. Apparently earthworm channels and termite galleries are major contributors to measured increases in hydraulic conductivity and infiltration in ZT. The chloride concentration profiles showed great variability within each treatment. Although the averaged profiles for each treatment showed that ZT had half the peak chloride value of TT and the peak occurred lower in the profile, these differences were not statistically significant. Nevertheless, the chloride data indicate that more deep drainage occurred under ZT probably through preferred pathways. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Sorptivity; Hydraulic conductivity; Image analysis; Chloride profiles

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1. Introduction

Zero till is commonly advocated as a preferred cropping system to conventional, multicultivation practices. Zero till is particularly attractive on clay soils, both to minimise compaction and induce natural structure formation. In particular, the soil structure of Vertisols has strong potential to attain optimal conditions for plant growth through activation of their in-built resiliency via shrink–swell cycles (McGarry, 1996, 1997; Pillai and McGarry, 1999). Articles and reviews on the benefits of reduced tillage systems are many. Thomas et al. (1997) provide a recent, comprehensive review that places concepts and practices of minimum tillage in context with the many types of conventional cultivation.

The aim of the current work was to identify reasons for the increased water storage in the untilled soil of a zero till field experiment. At the site, Radford et al. (1995) measured a 28% increase in plant-available soil water at sowing with zero tillage (ZT). Since water supply is a major factor limiting the yield of rainfed crops in the semi-arid, subtropical areas of central Queensland, a practice which improves soil water storage can potentially increase grain yields. At the trial site ZT outyielded traditional tillage by 1.2 t wheat grain per hectare per year during 4 years when fertiliser (N + S + Zn) was applied (Radford et al., 1995).

Radford et al. (1995) also showed there was a 4-fold increase in earthworm numbers with zero till compared to conventional tillage. Mele and Carter (1999) link the adoption of conservation tillage practices with increased earthworm activity; mulched stubble in particular favouring large increases in earthworm numbers. Retention of maximum levels of crop residues on the soil surface and lack of soil disturbance (ZT) apparently create a more favourable habitat for soil animals (Webb et al., 1997). Earthworm channels and termite galleries increase the volume of soil pores, which should increase aeration and the rate of water entry into the soil (Ehlers, 1975; Holt et al., 1993).

Image analysis of soil structure is gaining considerable use as both a pictorial and quantitative assessor of soil management effects. Moran et al. (1988) compared the effect of direct drilling and conventional cultivation for wheat in NSW, Australia. Cavanagh et al. (1991) compared the differences in pore structure attributes in a minimum till trial on a red-brown earth, in NSW, Australia. Wild et al. (1992) assessed the long-term effects of growing irrigated cotton on a Vertisol, with contrasting treatments of deep and shallow ripping and gypsum application. Douglas et al. (1992a,b) assessed the effects of wheel traffic on the growth of perennial grass in Scotland. Lytton-Hitchins et al. (1994) compared binary images and derived structure attributes of adjacent bio-dynamic and conventionally managed dairy pastures in Victoria, Australia. Pillai and McGarry (1999) used binary images and derived data to compare soil structure repair of a compacted Vertisol with four breakcrops and a range of wet–dry cycles.

In this paper we present the results of soil physical determinations and image analysis of soil structure from the traditional and ZT treatments of the Radford et al. (1995) experiment. The aim is to describe the soil physical changes induced by these two contrasting fallow management practices.

2. Materials and methods

2.1. Site

The site is located at the Biloela Research Station, Qld, Australia (latitude 24° 22’S; longitude 150° 31’E; altitude 173 m). Slope is negligible. The native forest was cleared in 1924, and crop and pasture were grown until 1983 when the experiment commenced. A meteorological station is located at the site. The soil is a black cracking clay (Vertisol) developed on alluvium; classed locally as Tognolini series (Shields, 1989). Selected soil physical and chemical properties are presented by Radford et al. (1995). In summary, particle size distribution to 0.9 m was uniform, averaging 45% clay, 19% silt and 36% sand. CEC was also quite uniform over the same depths, averaging 37 cmol(+)kg⁻¹.

The experiment consisted of four tillage treatments with four replications (Radford et al., 1995). In 1989, each plot was randomly split for four fertiliser treatments. The size of the main plots was 72 m × 22 m and of the split plots 18 m × 22 m. At the time of collecting the hydraulic measurements and soil image analysis samples, the traditional tillage treatment (TT) had received 34 tillage operations while ZT had
received no mechanical operations since 1983. There
had been four applications of herbicide on TT and 32
on ZT. All crop residues were retained but those in TT
were buried with a disc plough at the start of each
fallow.

2.2. Soil hydraulic properties

Hydraulic properties of the moist soil were mea-
sured by disc permeameter prior to sowing wheat.
Stubble was retained on the surface but clipped prior
to measurement. Sorptivity and hydraulic conductivity
at supply tensions of $-10$, $-20$, $-30$ and $-40$ mm
$H_2O$ were measured with disc permeameters (Perroux
and White, 1988) on two adjacent plots of TT and ZT.
These four tensions allow the filling of soil pores with
effective diameters smaller than 3.0, 1.5, 1.0 and
0.74 mm, respectively (Coughlan et al., 1991). For
each measurement, a level site was selected, a 200 mm
diameter and 3 mm high metal ring placed on the
undisturbed surface, and moist contact sand put in the
ring and smoothed flat. The ring was removed, a disc
permeameter placed on the sand pad, and the flow of
water into the soil measured with time. Each disc
permeameter was configured such that the four supply
tensions were applied to the one soil area from one
reservoir of water, first at $-40$ then $-30$, $-20$ and
finally $-10$ mm. Each tension was maintained until the
flow rate was approximately constant with time. At
the completion of the test, the sand pad under each
permeameter was scraped off the soil surface, and the
water content of the wet soil immediately beneath was
determined gravimetrically. An adjacent sample of dry
soil was also taken for determination of its water
content.

The cumulative inflow of water into the soil was
then plotted against the square root of time, and the
sorptivity was calculated from the slope of the line at
small values of time (Smettem and Clothier, 1989).
The cumulative inflow was also plotted against time,
and the hydraulic conductivity was calculated from
the slope of the line at large values of time (Smettem
and Clothier, 1989).

Estimates of pore densities were also calculated
from the disc permeameter data. By equating Darcy’s
Law and Poiseuille’s Law, the change in hydraulic
conductivity with each change in permeameter supply
tension can be translated into an equivalent density of
straight cylindrical pores of a certain size class
(Coughlan et al., 1991). The diameters of the size
classes were 3.0–1.5, 1.5–1.0 and 1.0–0.74 mm,
equating to the change in supply tension from $-40$
to $-30$, $-30$ to $-20$ and $-20$ to $-10$ mm, respec-
tively.

Water infiltration parameters were measured with
an oscillating nozzle rainfall simulator and vacuum
tank runoff collection (B.J. Bridge and D. Orange,
pers. commun.) on the same two adjacent plots of TT
and ZT as the disc permeameter measurements. Crop
residues on the surface were retained during the rain-
fall simulator tests. There were three simulations per
plot. For each simulation, sub-plot edges 1 m × 1.6 m
were driven 100 mm into the ground, and front collec-
tion troughs installed. One sub-plot was covered with
a shade screen mesh to provide low-energy rain and
the other sub-plot was left uncovered to provide high-
energy rain. Rain was then applied at 100 mm h$^{-1}$
for 1 h and the following parameters recorded: time to
ponding (min), infiltration rate after 100 mm of rain
(mm h$^{-1}$) and total infiltration after 100 mm rain
(mm).

2.3. Image analysis of soil structure

Intact samples of soil from the top 0.24 m of the soil
were collected at the same time and from the same two
adjacent plots of TT and ZT as the disc permeameter
and infiltration data. Three open-ended, ‘cubes’
(120 mm × 120 mm × 120 mm high) of perforated
steel were hydraulically pushed into the soil. The
cubes were pushed into the soil in a line with a
maximum 1 mm gap between them. These were care-
fully excavated and sealed in polythene bags. A
second row of cubes was then placed on the soil at
0.12 m, ensuring each of the three cubes was located
immediately beneath those taken in the 0–0.12 m
layer, and pushed into the 0.12–0.24 m layer. The
cubes were excavated and sealed in polythene bags.
During excavation of the cubes soil samples were
taken in 0.04 increments to 0.12 m, and in 0.06 m
increments from 0.12 to 0.24 m for gravimetric water
content determination. This was important as porosity
in Vertisols is strongly affected by water content
(McGarry, 1997).

The cubes were impregnated with an epoxy resin
mix (Moran et al., 1989), sectioned with a diamond
saw after curing and subjected to image analysis (Moran et al., 1989). Outputs were digital binary images and four structure attributes (McBratney and Moran, 1990). In brief, porosity is the proportion of pore (black) to solid (white) pixels, surface area is an estimate of the number of pores for each depth increment, and solid and pore star length are the average horizontal length of soil solid and pore, respectively. The binary soil pore image for each cube was $512 \times 512$ pixels over a $120 \text{ mm} \times 120 \text{ mm}$ area; giving a resolution of $234 \mu \text{m}$ per pixel. The data for the attributes were analysed using univariate analysis of variance. The experimental design was a factorial with one factor, split for depth with three duplicates (the three cubes). Data were averaged over selected depth increments, to facilitate the analysis of variance. Averaging was done in $0.1 \text{ m}$ layers from the soil surface, and the resultant data plotted at $0.05$, $0.15$, $0.25 \text{ m}$, etc. The following formula were used for averaging (1–4, here, are Eqs. (1), (2), (6) and (7), respectively, from McBratney and Moran, 1990):

1. **Porosity**: Porosity is defined as

$$L_{p} = \frac{L_{p}}{L_{T}},$$  \hspace{1cm} (1)

where $L_{p}$ is the number of black pixels in a test line, and $L_{T}$ the total number of pixels in the test line. Since $L_{T}$ is common across all rasters in the image, the average porosity over a selected number of test lines is the mean porosity for these test lines.

2. **Surface area**: Surface area is defined as

$$S_{v} = 2I_{L},$$ \hspace{1cm} (2)

where $I_{L}$ is the number of pore to solid intercepts per unit length of test line. Similar to porosity, the denominator is common for each test line, so the average surface area over a selected number of test lines is the mean surface area for these test lines.

3. **Pore and solid star length**: Pore star length is defined as

$$l_{p} = \frac{2}{L_{p}} \left[ P(l_{0})_{p} + \frac{\max L}{2} + \sum_{i=1}^{\max L} P(l_{i})_{p} \right],$$ \hspace{1cm} (3)

and solid star length as

$$l_{s} = \frac{2}{1-L_{p}} \left[ P(l_{0})_{s} + \frac{\max L}{2} + \sum_{i=1}^{\max L} P(l_{i})_{s} \right],$$ \hspace{1cm} (4)

where $l_{p}$ and $l_{s}$ the expected continuous length of pore and solid in the horizontal plane, and $P(l_{i})$ the proportion of pore or solid pixels present after $i$ erosions of length one. Since $L_{p}$ (and hence $1-L_{p}$) is not constant between test lines there is a need to form weighted averages for $l_{p}$ and $l_{s}$ to determine the true mean over a selected number of test lines. The average pore star length over $x$ raster lines

$$l_{p(\text{av})} = \frac{\sum_{i=1}^{x} L_{Lp(i)}l_{p(i)}}{\sum_{i=1}^{x} L_{Lp(i)}},$$ \hspace{1cm} (5)

and the average solid star length

$$l_{s(\text{av})} = \frac{\sum_{i=1}^{x} (1-L_{Lp(i)})l_{s(i)}}{\sum_{i=1}^{x} (1-L_{Lp(i)})}. $$ \hspace{1cm} (6)

2.4. **Soil chloride content at depth**

Concentrations of chloride in the soil (mg kg$^{-1}$) were measured in all TT and ZT plots in $0.3 \text{ m}$ increments to a depth of $4.5 \text{ m}$. Eight profiles per treatment (two per plot) were taken using $50$ and $38 \text{ mm}$ diameter push tubes and a hydraulic rig. The aim was to determine the net effect on soil chloride concentrations of different hydraulic conductivities after a period of 10 years of treatment application.

3. **Results and discussion**

3.1. **Sorptivity**

The sorptivity of the surface soil in the TT and ZT treatments is shown in Fig. 1a. The distribution of sorptivity with supply tension was quite different for the two treatments. Sorptivity for ZT at the $-10 \text{ mm}$ supply tension was significantly ($P = 0.05$ and throughout the script, unless otherwise stated) greater than the sorptivity at each of the $-20$, $-30$ and $-40 \text{ mm}$ supply tensions of that treatment, though none of these three were significantly different from...
each other. In contrast, the sorptivity for TT was significantly less than ZT at \(-10\) mm supply tension, then TT had smaller decreases in sorptivity as supply tension changed from \(-10\) to \(-30\) mm.

Sorptivity is a measure of the soil’s ability to absorb water under capillary forces independent of gravity, and as such indicates the pore volume being filled in the early stages of infiltration. Thus ZT had the greater pore volume filled at \(-10\) mm supply tension, i.e., the largest pores (diameters between 1.5 and 3.0 mm) measured with this technique. This is supported by the very low sorptivities for ZT at \(-20\), \(-30\), \(-40\) mm supply tensions. The TT treatment had a more even spread of sorptivity, showing the greater dependency of water absorption in that soil of pores \(<1.5\) mm diameter, i.e., pores of the middle and smallest size classes measured.

### 3.2. Hydraulic conductivity

The hydraulic conductivity of the surface soil in the two treatments showed a similar pattern to the sorptivity (Fig. 1b). Logarithmic transformations were used because the data were log-normally distributed, particularly at the \(-10\) mm supply tension. For both treatments, the hydraulic conductivity at \(-10\) mm supply tension was significantly greater than at the other three tensions. In TT, the hydraulic conductivity at \(-20\), \(-30\) and \(-40\) mm supply tensions were significantly greater than in ZT, while at \(-10\) mm supply tension, ZT had significantly greater hydraulic conductivity.

These results reflect the size distribution of the filled pores during the permeameter tests. The larger volume of filled pores 3.0–1.5 mm in diameter (i.e., the largest size class measured) in the ZT treatment resulted in a very great hydraulic conductivity.

The pore densities for the two treatments, as calculated from the hydraulic conductivity data, are presented in Table 1. ZT had a significantly greater density of pores 3.0–1.5 mm in diameter than the TT treatment; almost 7-fold greater in number. These large pores were easily observed in the field in the form of termite galleries and earthworm burrows. ZT had the greatest population of termites and earthworms (Radford et al., 1995) and their galleries and burrows (average observed diameter of 3 mm) tended to remain intact due to the lack of soil disturbance. Termite galleries at the site ranged in size from 2 to 8 mm, with larger, flattened galleries up to 75 mm x 75 mm in cross section and 8 mm long.

<table>
<thead>
<tr>
<th>Pore diameter classes (mm)</th>
<th>TT</th>
<th>ZT</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.0–1.5</td>
<td>2.8 (1)</td>
<td>20.7 (2)</td>
</tr>
<tr>
<td>1.5–1.0</td>
<td>3.7 (1)</td>
<td>5.2 (1)</td>
</tr>
<tr>
<td>1.0–0.74</td>
<td>26.8 (2)</td>
<td>9.5 (1)</td>
</tr>
</tbody>
</table>

*a* Means with the same number in parentheses are not significantly different \((P < 0.05)\).
occuring at depths greater than 250 mm (Holt et al., 1993). On the other hand, the TT treatment had a significantly greater density of pores of the smallest size determined (1.0–0.74 mm diameter) than the ZT treatment.

### 3.3. Infiltration of simulated rain

The three infiltration parameters measured with the rainfall simulator for TT and ZT are presented in Table 2. The time to ponding was significantly greater in ZT than TT with no significant effect of rainfall energy. Under low-energy rain (the soil was covered by a shade screen mesh), both the final infiltration rate and the total infiltration after 100 mm of rain were significantly greater in TT than ZT. However, ponding on a sub-surface layer below the depth of cultivation was observed in TT during the simulator runs. This led to leakage under the plot edges, resulting in low runoff rates and apparently large infiltration. Under high-energy rain (the soil was not covered), a strongly visible surface seal developed in TT. Sub-surface ponding did not occur and the TT treatment had both significantly less final infiltration rate and total infiltration than ZT.

The results of the rainfall infiltration indicate the strong, positive effect of surface cover on infiltration, as found by Freebairn et al. (1986). In ZT, the stubble cover protected the soil surface from raindrop action, so no change in infiltration occurred when the applied rainfall was changed from low-energy to high-energy. On the other hand, such a change in rainfall energy in TT dramatically decreased both the final infiltration rate and the total infiltration during the simulator test, apparently from raindrop action sealing the unprotected soil surface. Natural rainfall in this region is commonly high-energy storm rainfall, and the superior infiltration into the ZT treatment under such (simulated) conditions is quite evident. More generally, sealing of the soil surface from raindrop impact under the rainfall simulator explains the far lower final infiltration rate obtained in that way compared to the −10 mm hydraulic conductivity from the disc permeameter data.

### 3.4. Image analysis of soil structure

At the time of sampling, ZT was more than twice as wet as TT in the 0–0.04 m layer and remained wetter throughout the profile to 0.24 m (Fig. 2).

![Fig. 2. Soil water content of TT and ZT soil profiles at the time of sampling for image analysis.](image-url)
The binary images of the cut vertical faces from the two treatments show marked contrasts in the size, shape and location of pores (black) in the profile (Fig. 3a and b). These differences are complemented by the means and significance of differences between means of the two treatments (Fig. 3c). The treatment × depth interaction for each of the four attributes was highly significant: $P = 0.001$ for porosity, surface area and solid star length, and $P = 0.004$ for pore star length. The source of these significant interactions is most evident in Fig. 3 both in the digital images and the attribute plots. Three layers are evident, with an obvious reversal of trend in the data between the zones.

In the 0.01–0.02 m layer porosity was more than double in ZT than TT, reflecting the obvious soil crust in the surface 0.025 m of TT. In contrast, the surface 0.03 m of ZT consisted of strongly aggregated material, surrounded by abundant, interconnected pores. The more continuous pores in ZT are reflected in the significantly greater pore star length for ZT in the 0.01–0.03 m layer. It should be remembered that ZT demonstrates greater porosity than TT despite being more than twice as wet at time of sampling. In Vertisols, such as at this site, increased water content generally corresponds to lower porosity due to soil swelling. The greater porosity in the wetter soil of ZT may demonstrate that the aggregates and porosity in ZT are more stable than in TT, remaining large and open, despite large water contents.

In the 0.05–0.1 m layer, the trend in the surface soil was reversed. TT had up to 5-fold more porosity than ZT, composed in part of many small pores, as demonstrated by the strongly significant increase in surface area for TT in this layer. ZT was dominated by continuous soil solid, shown by the significantly larger solid star length. This zone is most evident in the binary image, where TT has more porosity composed

Fig. 3. A binary image of (a) traditional tillage and (b) ZT soil profiles with (c) depth functions of the means of the analysed attributes of porosity, surface area, pore star length and solid star length. In all images black is soil pore and white is soil solid. The letter “A” in the image of TT highlights sharp edges on high-density soil units, as discussed in the text. The significance of the difference between the means of the two treatments for a given depth is given as (**), (*) or (●): which are $P \leq 0.01$, $P \leq 0.05$ and non-significant, respectively.
of small to large pores whereas ZT has fewer pores some of which appear round in section. However, also evident in the images (but not in the attribute data) is the presence of sharp edges on the face of high-density (white) soil units (labelled “A”) in this layer of TT (Fig. 3a). A cultivation disc cutting wet soil is a probable cause.

In the 0.15–0.2 m zone the trend in the layer above is again reversed where, though not significant, porosity in ZT is up to 10-fold that of TT (e.g. 19.2 vs. 1.9% in the 0.18–0.2 m layer). The combination of significantly greater surface area and significantly smaller solid star length for ZT shows ZT has more small pores and smaller soil unit width than TT. This is most evident in the binary image, especially the relatively greater density of TT below 0.15 m, relative to the finely porous soil in ZT. This may be the sub-

surface layer that was seen to reduce water infiltration in TT during the rainfall simulator study.

The dynamic nature of the porosity in ZT is most visible when the vertical, cut faces of the six cubes are laid-out in their field-order (Fig. 4). This triptych clearly shows the three zones discussed above. There are vertical pores, from the soil surface to almost 0.2 m. These, together with the many circular pores in the 0.05–0.19 m layer, correspond well with the high earthworm and termite counts in ZT (Radford et al., 1995). The 0.16–0.24 m layer is typified by abundant pores between finely aggregated soil material. Overall, there is strong evidence in ZT for intense earthworm activity giving cast material on the surface, continuous vertical and horizontal channels throughout the profile, and finely aggregated earthworm cast material in the 0.16–0.24 m layer.
3.5. Chloride profiles

The average chloride (Cl) concentrations down the soil profile in the TT and ZT treatments are shown in Fig. 5. The TT treatment had a peak Cl concentration of around 400 mg kg\(^{-1}\) at a depth of 2.5 m, while the ZT treatment had a peak Cl concentration of 220 mg kg\(^{-1}\) at a depth of 3 m. The difference in peak concentration was not significant as there was large variability between individual profiles. This was particularly true in the ZT treatment where peak Cl concentrations ranged from 9 to 653 mg kg\(^{-1}\) and the depth of the peak ranged between 2–4.2 m (Table 3). Nevertheless, the Cl data indicate that more deep drainage occurred under ZT.

![Fig. 4. Binary images of the three zero till soil profiles, laid out in field order.](image_url)

### Table 3

<table>
<thead>
<tr>
<th>Profile Number</th>
<th>Traditional till</th>
<th>Zero till</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Peak value (mg kg(^{-1}))</td>
<td>Depth (m)</td>
</tr>
<tr>
<td>1</td>
<td>738</td>
<td>3.0–3.3</td>
</tr>
<tr>
<td>2</td>
<td>549</td>
<td>2.4–2.7</td>
</tr>
<tr>
<td>3</td>
<td>528</td>
<td>2.4–2.7</td>
</tr>
<tr>
<td>4</td>
<td>492</td>
<td>1.5–2.1</td>
</tr>
<tr>
<td>5</td>
<td>450</td>
<td>2.1–2.4</td>
</tr>
<tr>
<td>6</td>
<td>411</td>
<td>2.7–3.0</td>
</tr>
<tr>
<td>7</td>
<td>390</td>
<td>1.8–2.1</td>
</tr>
<tr>
<td>8</td>
<td><strong>10</strong></td>
<td><strong>a</strong></td>
</tr>
</tbody>
</table>

*No single depth at which a peak clearly occurred.*
Deep drainage, linked here to measured increased infiltration, is regarded as a positive attribute of zero till. Grain growers in the vicinity of the current trial have observed that a major advantage of reduced tillage is increased cropping frequency. That has only become possible due to the increased water storage resulting from reduced tillage. Increased frequency of cropping could potentially reduce through-drainage as crops occupy the ground for longer, utilising stored soil water. The deep drainage results in the current trial can be attributed to inadequate cropping frequency in the zero till treatment.

4. Conclusions

Zero till, relative to traditional tillage practices, has given marked differences in soil physical properties of a Vertisol in the semi-arid subtropics of Australia. In this environment and cropping system, high water storage in the soil profile during the fallow period is of paramount importance, particularly to increase the incidence of opportunity cropping. Previous work at this site has shown zero till achieved a 28% increase in plant-available soil water at sowing and an associated increase of 1.2 t wheat grain per hectare per year. The cause was strongly evident in the current work. Evidence of earthworm and termite activity increased greatly in the zero till treatment. The incidence of faunal, interconnected soil pores from the soil surface to depth was strongly evident in the image analysis. The outcome was a large increase in sorptivity and hydraulic conductivity of the zero till plots with the major contributors being large (3 mm) pores. These pores were scarcely present in the traditional till.

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