Rapid assessment of soil compaction:

Using a Soil Moisture - Density Gauge to determine contributions of compaction to losses in field crops

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Summary

- A study was conducted to evaluate:
  - Whether a Troxler* Soil Moisture-Density Gauge can give a valid measure of soil density in cropping fields.
  - Whether soil density is altered by cultivation practices and if it affects yield.

- The project was funded by the MAF Sustainable Farming Fund, Foundation for Arable Research, Hawke's Bay Regional Council and LandWISE Inc.
  - Field work and project management was conducted by Dan Bloomer
  - Data analysis and calibration protocol development was by Bruce Searle

- Results suggest that the Troxler can give valid measures of soil density but must be calibrated for each soil type and depth. A protocol for calibration purposes is presented.

- Once calibrated, the Troxler offers the advantage of quickly collecting a large number of soil compaction measurements at different depths. It greatly reduces the labour of physical soil sampling and sample processing. Being non-destructive it allows repeat sampling in the same positions.

- Studies of four farm paddocks found that conventional cultivation and ripping tended to decrease soil density in the 150-300mm soil depth. However, this decrease in density did not result in increased yields.

- Only at one site (Bulls) was yield limited by high soil compaction. At other sites, there was no effect of soil density on yield, but in some cases this may have been because factors other than soil density were limiting.

- Soil densities at Bulls were not significantly higher than at other sites. Determining how density limits yields and under what conditions is necessary for an understanding of when mitigation options will be beneficial to yields. The use of a properly calibrated Troxler will allow the detailed measurements of soil density to help address this issue.

Fig.1 View of Troxler 3440 Neutron Densometer with source set at 300mm soil depth

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Project Brief

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Project description

This project evaluated the ability of Soil Moisture-Density Gauge technology to assess soil compaction in cropping fields. It was also used to assess compaction and some options for alleviation in a selection of fields.

The issue/opportunity

LandWISE farmers identify soil compaction as a key concern. Compaction was found to be the single biggest factor causing 'failures' in strip till or no-till crops and is present in most conventional cultivated fields as well.

Compaction reduces yields but is difficult to assess. It is also difficult to determine optimal strategies for remediation, an expensive process. All farmers are faced with compaction issues, but need better information for better decisions. Consultants have difficulty providing quick repetitive assessments of compaction so are unable to give needed advice. Compaction is expensive, but so is failure to address it.

Previous work investigating soil compaction has been undertaken by Landcare, FAR, Crop&Food Research and others. Significant yield penalty was typical in such cases.

LandWISE research during SFF 03-095 found soil compaction induced penetration resistance greater than 1.5MPa is common. Adverse effects were observed in squash, sweet corn and maize.

Context

Nevens and Reheul (2003) found soil compaction reduced maize silage yield by 13% and nitrogen uptake by 23% when penetration resistance was up to 1.5MPa. The yield loss was very significant and reduced nitrogen uptake left suboptimal nitrogen content in silage.

If only 10% of maize grain crops lose 13% of yield, soil compaction costs the maize grain industry (31,000 ha planted, gross value $70M) over $0.9 Million pa in lost revenue. Similar losses in silage imply the national losses may be double this figure.

Less strongly rooting crops may suffer greater losses. 10% of squash (6,000ha planted, FOB value $55M) and sweet corn (6,000ha planted, FOB value $50M) losing 13% of yield, equates to over $1.3 Million exports lost annually. These figures may be conservative.

Measurement of compaction usually takes bulk density cores or measures penetration resistance. Bulk density cores are time consuming to take and process, and as they are destructive, cannot be repeated in the same place. Penetration resistance is highly dependent on moisture, and varies over time.

Troxler Soil Moisture-Density Gauge technology allows quick and simple measurement of bulk density, soil moisture and porosity with very little soil disturbance.

Background

Botta et al (2004) used the Troxler technology to assess in-field compaction and measured yield losses of 38% from tractor compaction of no-till soya fields.

The Troxler Model 3440 is a portable Surface Moisture-Density Gauge containing two separate radioactive sources. These enable the equipment to rapidly determine both soil density and soil moisture content.

If used correctly, no significant hazard exists from the equipment in normal operation. The device does contain radioactive materials, and therefore does pose a potential hazard. Operators are required to be suitably trained and equipment is registered with the National Radiation Laboratory.

Density Measurement

The Troxler 3440 uses gamma radiation emission from a cesium-137 source for soil density measurement. Detectors in the base of the gauge measure the radiation.

Gamma photons released by the source collide with electrons in the soil. This reduces the number of photons reaching the detector, and thus allows the density of the material to be calculated.

The Troxler uses two modes of transmission: direct transmission mode (with the source rod extended down into the soil matrix) and backscatter mode (with the source rod retained within the gauge main housing.

In direct transmission mode, photons must pass through the full volume/distance of soil between source and detector. The number of photons reaching the detector is a true average of the density of soil between source and detector.

Methods

Part 1 Assessment of the methodology.

The system was calibrated taking both Troxler measurements and physically extracted 85mm diameter soil bulk density cores to ensure validity on key soil types.

The method was used in conjunction with seed bed assessments to help isolate causes of crop variability.

Part 2 Comparing remediation strategies.

The technology was used to assess the effectiveness of soil compaction remediation, including aerating before and after cultivation and planting.

Part 3 Field surveys

Surveys of compaction and penetration resistance in cropping fields were intended to determine the spatial and temporal presence of compaction limiting root development. This was not able to be effectively completed as we did not identify definitive compaction limits.

Introduction

Soil density can have serious effects on crop growth, limiting root penetration, water and nutrient availability and thereby decreasing yield. Managing and mitigating soil compaction effects are necessary for sustainable production.

However, studies on soil compaction are limited in scope because of the labour intensive sampling for recording soil compaction.

This survey study is an attempt to evaluate the use of a rapid non-destructive method of soil density. The Troxler gauge uses gamma-neutron radiation as a measure of density.

As well as determining the usefulness of the Troxler as a measure of soil compaction, it was used to evaluate tillage effects on soil compaction, and to determine if certain areas of paddocks exposed to heavy traffic loads were compacted and limiting to yield.

Troxler Operation

The operating procedures for the Troxler 3440 Soil Moisture-Density Gauge are well documented in the Troxler Manual. The equipment consists of the gauge and its incorporated electronics and radiation sources and readers, a polyethylene reference block for equipment calibration, and a plate and drill rod to establish a hole down which the source rod is fed into the soil matrix.

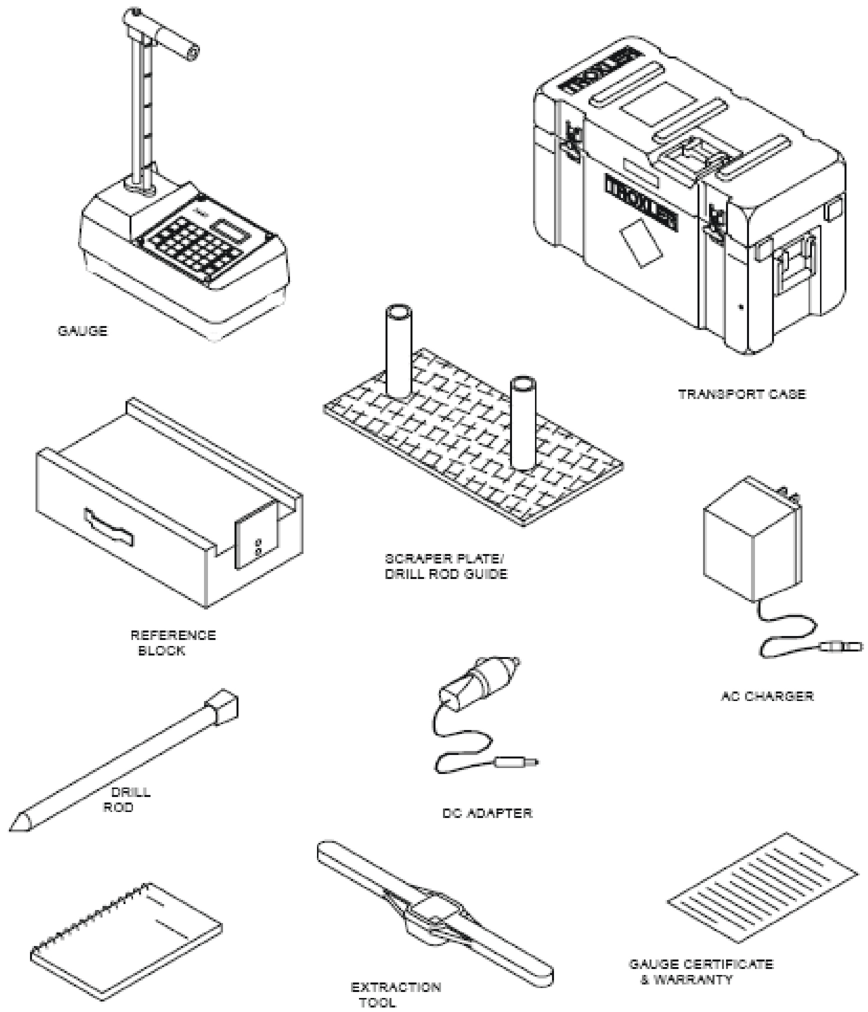

Fig.2. Troxler Soil Density-Moisture Gauge standard equipment (Source: Troxler 3440 Manual)

In setting up the equipment, consideration is given to the time duration of readings. Three standard settings are 15 seconds, 1 minute, and 4 minutes. The longer reading is generally most accurate, but one minute readings are generally considered satisfactory.

The gauge will present measurement data either as raw counts or as calculated density and moisture percentages. The calculated values were recorded for the main field work undertaken in this project. However, subsequent analysis of the collected results showed that raw counts are better and this has become one of the recommendations in this report.

The radioactive sources in the gauge are Cesium-137 and Americium 241:Beryllium which have half lives of 30 and 432 years respectively. To account for the decay, standard counts are taken at the start of each day of use. The polyethylene standard block is used to provide a standard count. The measured reading is automatically compared to the average of the previous four standard count readings and the calibration set accordingly.

Once the equipment is set up, site readings can be made. The ground surface conditions are critical to gauge performance and test results. In common use, the aim is to establish the density of the soil matrix in road construction or similar. In such cases voids have largely been eliminated, and allowing surface roughness to create apparent voids will skew results incorrectly. Sand can be use to fill minor voids to improve reading reliability.

Variation to Standard Practice

In this study, the mean density of a cultivated field, which at times includes cultivation rubble, was sought. Rather than fill voids with sand, the surface was carefully scraped to ensure best contact between the gauge and the soil surface, but minor roughness was allowed to remain. The assumption was that such voids existed in the cultivated root zone.

The supplied scraper plate and drill rod were used to establish a hole for the source rod.

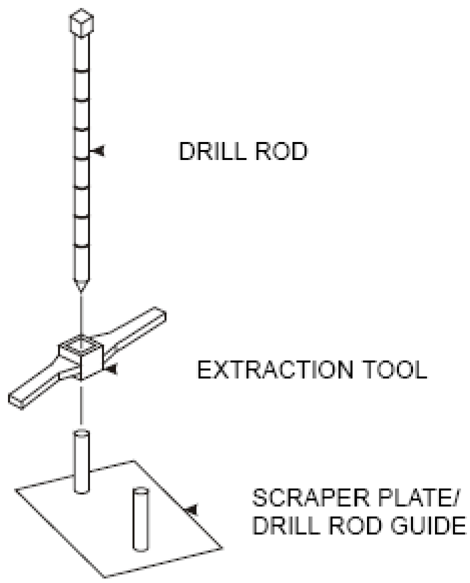

Fig.3. Drill rod and extraction tool with scraper plate (Source: Troxler 3440 Manual)

In field trials, readings were made in the in-row and inter-row positions. Particularly where strip–tillage had been employed, the soil density in the two zones might be assumed very different. The method adopted in most cases was to use the same access hole, but to reverse the placement of the gauge body so that different soil sections were measured.

Fig. 4. Position of Gauge for in-row (left) and inter-row (right) Soil Density-Moisture measurements

Comparative soil density measurements were made using a standard soil bulk density corer, taking 85mm cores 150mm long. Some difficulty was experienced determining the exact depth for coring using this method, including assessing the degree of surface distortion when the corer was hammered into the soil.

Fig. 5. Sampling using bulk density soil corer: Installation (left) and extracted core (right)

The Troxler was initially used at the Centre for Land and Water (Ruahapia) to compare machine soil density and moisture readings with gravimetric assessments of physically extracted 85mm soil bulk density cores.

The main trials involved assessments of soils at four cropping farms; at Manutuke (clay loam) and Bulls (sand), and at Otane (silt loam) and Ashcott (silt loam). In the first two cases, significantly different growth of young maize plants was evident, and the patterns suggested soil factors had influence. In the third and fourth, different cultivation treatments had been applied. At Otane, an area of the field had been deep ripped to alleviate any compaction. At Ashcott, part of the field was conventionally cultivated and the other strip-tilled.

At Manutuke, areas of small plants within a field did not correlate with planter/fertiliser equipment or meso-topography, but were possibly associated with traffic areas. At Bulls, smaller plants appeared to have possible relationship to topography, with smaller plants in highest and lowest areas on rolling sand.

Unfortunately, by the time clear differences were identified in these fields, side dressings had just been applied. Fertility testing of discreet areas did not show any significant nutritional differences, but possible nutritional differences caused by starter fertiliser variations may have been lost.

Part 1. Does the Troxler give valid soil density data?

- The validity of Troxler data was analysed by examining the relationship between the value of dry soil density measured with Troxler against value of dry soil density measured by taking a sample in the standard way
- Values were measured on different soil types in different regions
- The relationship using data from all 5 sites is shown in Figure 6. The regression has an r^2 value of 64%, and most values fall within the 95% prediction lines (data will be within these line 95% of the time).
- The sites have different variability, with Otane showing the greatest variability and the poorest correlation between Troxler measurement and physical measurement.

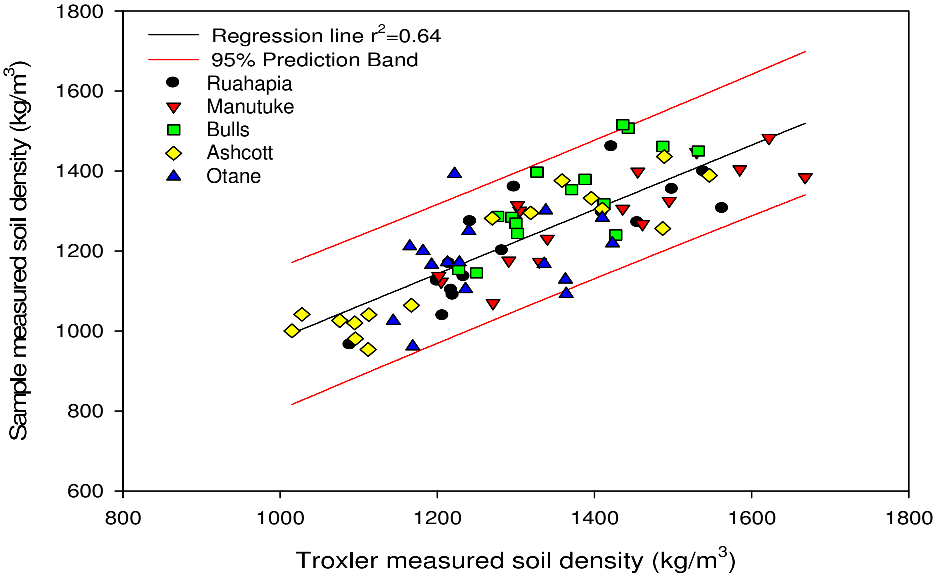

Figure 6. Relationship between Troxler and physical measurements of soil density for a range of sites. Regression equation is y = 177 + 0.81X.

- There is a general trend that higher values measured by the Troxler equate with higher physically measured values. Note however, that there is a reasonable amount of variability. For instance a Troxler measurement of 1400 kg/m3 could equate to a physical measurement ranging from 1150 to 1520 kg/m3. This is a large range, suggesting that there may be errors associated with the use of Troxler methodology. It should be noted that spatial variability of soil density is known to be low[1].
- The relationship did not improve significantly when Site was included in the regression analysis.
- However, further analysis shows that most of the variability was in samples measured in the 150-300 mm soil depth (Fig. 7). Including soil depth in the regression analysis did improve the fit (r^2 84%).

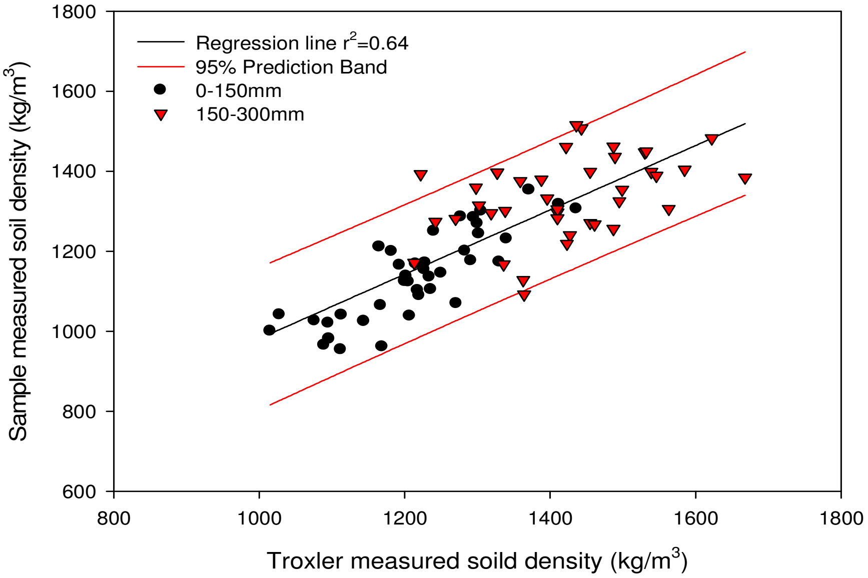

*Figure 7. Relationship between Troxler and physical measurements of soil density for different soil depths. Regression equation is: soil density = 0.804*Troxler density + 176.6*

- A regression was carried out on the relationship for each soil depth separately (Fig. 8). The results show that there is significantly greater variation for the soil measurements from 150-300mm depth but much less variation for measurements from 0-150 mm depth.
- This data suggests that Troxler measurements may give good estimates of soil density when sampling to a depth of 150mm. However, at depths of 150-300mm there is too much variability and a poor relationship (r^2 15%).
- The Troxler uses changes in the attenuation of gamma rays to measure the soil's wet bulk density and soil water content. It then uses these values to estimate the dry bulk density. The calibration of the attenuation of gamma rays is factory based and may not be appropriate for different soil types, particularly at depths greater than 150mm.

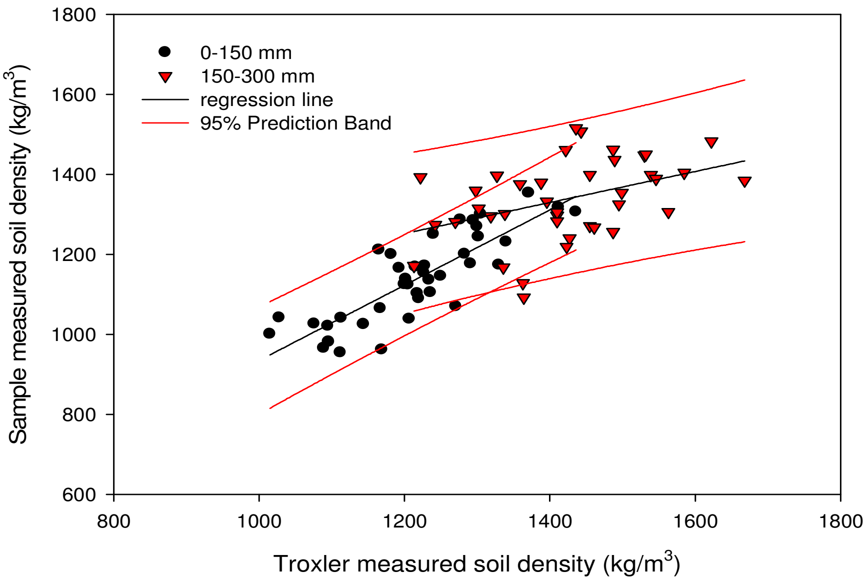

Figure 8. Relationship between Troxler measurements of soil density and physical measurements of density for different soil depth.

Validation and calibration

- Additional sampling was undertaken on two further soils (Twyford silt loam and Mangateretere silty clay loam) for the purposes of calibration.
- Predicted densities were calculated from Troxler measurements using the relationship between all soils (given in Fig. 7). These predicted densities were then compared to soil core measured densities from Twyford and Mangateretere soils. In neither soil did this approach give a good relationship between Troxler measure and actual soil density (Fig. 9 and Fig. 10).
- Instead of using the factory calibration for the prediction of density, calibration for Twyford and Mangateretere soils were carried out, using actual gamma counts and measured soil volumetric water[2]. The parameters of the calibration differed with depth and soil and significantly improved the fit (Fig 11 and 12).
- This confirms that calibration is necessary for accurate measurement of soil density using the Troxler equipment. A standardised calibration protocol should be developed. A draft protocol is presented below.

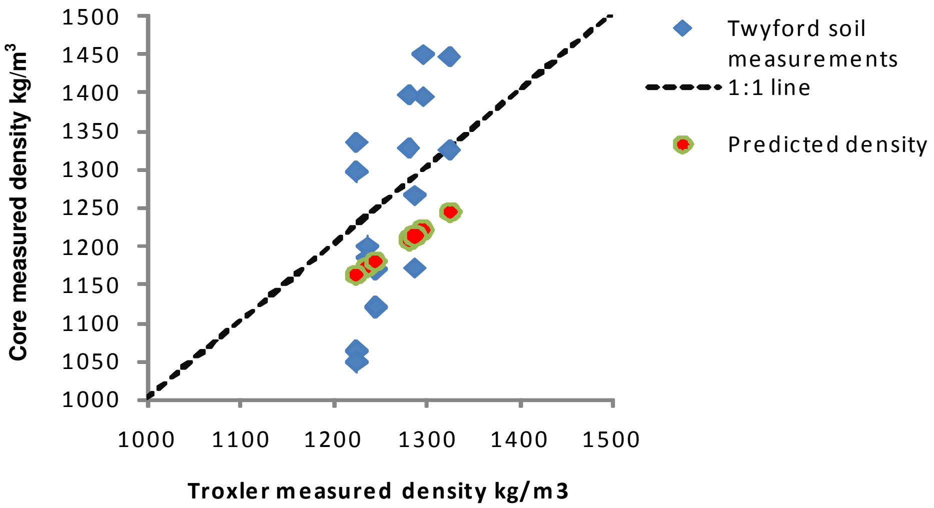

Figure 9. Relationship between Troxler measured density and core measured soil density for Twyford soil. The red dots indicate the predicted density from the general relationship established in Fig 7.

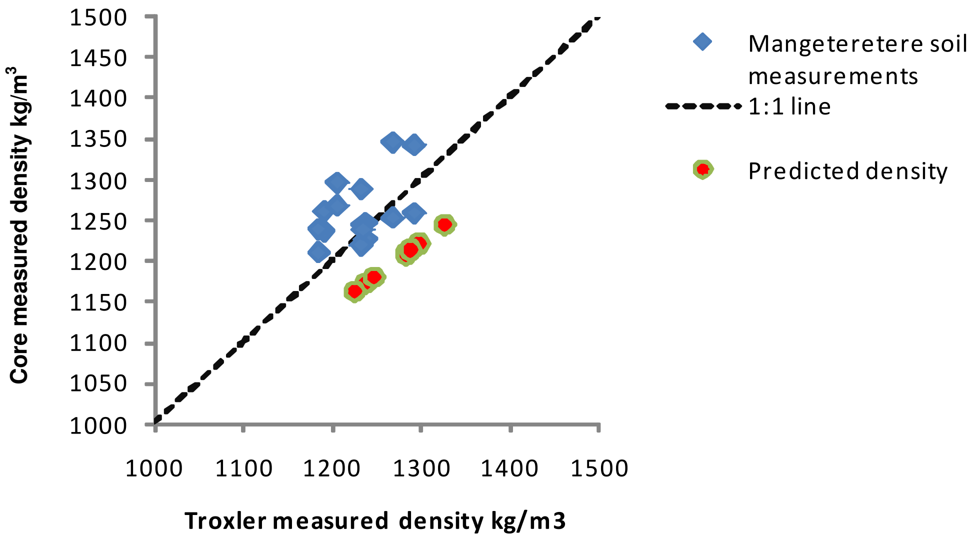

Figure 10. Relationship between Troxler measured density and core measured soil density for Mangaterere soil. The red dots indicate the predicted density from the general relationship established in Fig 7.

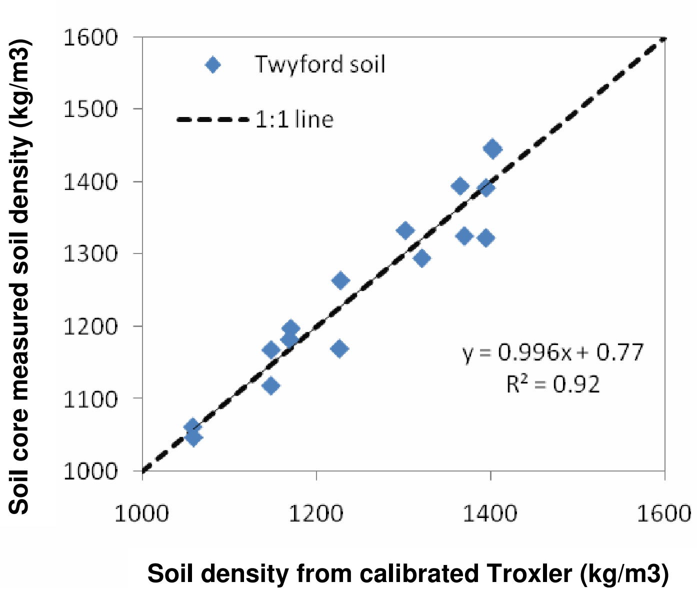

Figure 11. Relationship between estimated soil density obtained using individual soil calibration and soil core measured density for Twyford soil.

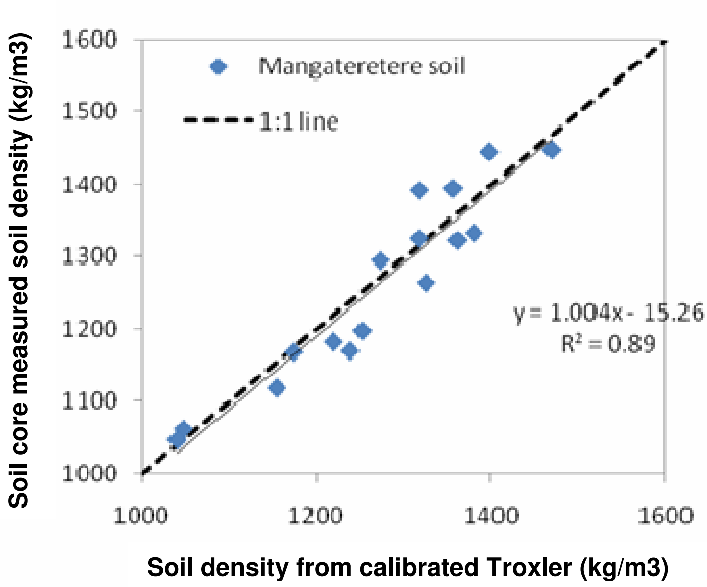

Figure 12. Relationship between estimated soil density obtained using individual soil calibration and soil core measured density for Mangateretere soil.

Draft Protocol for calibration of Troxler in-field

To calibrate the Troxler for different soils, counts must be recorded rather than values presented based on factory calibrations.

Counts must be the gamma- ray count

- without an intervening soil sample - most easily obtained from Troxler manual. If glass standards are available, then this count should be confirmed before starting.
- and the count at the detector with an intervening soil sample of known depth

To obtain the calibration

1. Record gamma ray count at detector for a known depth of soil. Soil should be moist, but not wet
2. Record Troxler measure of soil water content
3. Collect soil core sample to known depth; 4 cores in the Troxler measurement site are suggested
4. Record wet bulk density and volumetric water content
5. Record dry bulk density
6. A small area of the paddock (approx 2m^2) should be watered and allowed to drain to field capacity (or repeated after a heavy rainfall or irrigation event)
7. The measurements 1-5 outlined above should be repeated in this area

The aim should be to get counts for the soil moisture ranges that are likely to be encountered in the field. The number of repetitions for accuracy still needs to be determined.

The data of counts, soil bulk density and volumetric water content can then be used to develop the calibration equation described by Culley and McGovern[2].

To measure soil density to a known depth,

1. Record counts of gamma rays from Troxler
2. Record Troxler volumetric soil content measurement
3. Insert these into calibration equation for calculation of soil density.

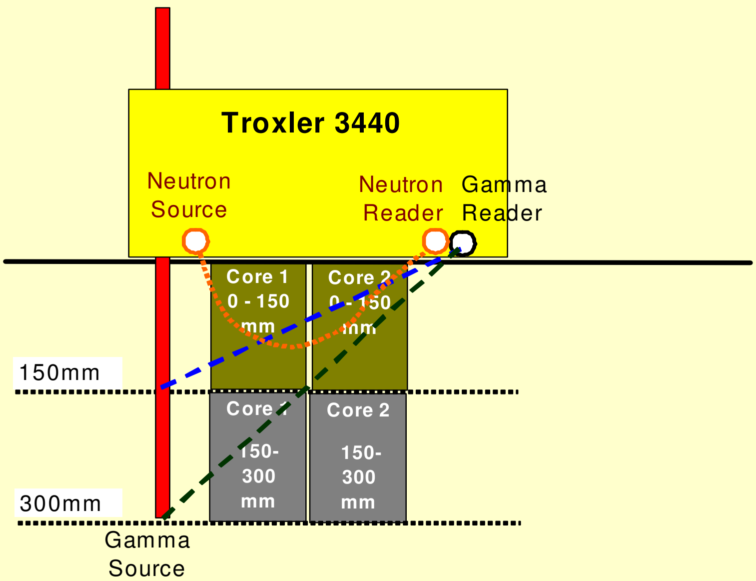

Figure 13. Schematic of Troxler and physical core sample positions as taken for soil calibration purposes

Part 2: Altering soil density and effects on yield

- In two paddocks (Manutuke and Bulls), four sets of replicated measurements were taken, comparing areas that appeared to be compacted with areas were there appeared to be no compaction.
- At two other sites (Otane and Ashcott), four sets of replicated measurements were taken, comparing the effect of cultivation practices on soil density:
    - o The effect on soil density and growth of strip-tillage compared to conventional cultivation (Ashcott).
    - o The effect on soil density and subsequent crop growth of deep ripping compared to no deep-ripping (Otane).
- Measurements of soil density for each treatment or area were recorded using the Troxler, as well as physically extracted 85mm diameter soil cores. Measurements of plant yield were collected in the different areas.
- Results were analysed using the complete data for soil density collected with the Troxler equipment. This provided a more comprehensive data set than the physical core values for each treatment or paddock location. Troxler data consisted of at least 5 measurements of soil density from 0-150mm and from 150-300mm depth from each replicate. All data was analysed with Genstat statistical analysis package.

Comparing areas within a paddock - Manutuke

- Maize plant data was collected from areas within the paddock where compaction appeared to be non-limiting to growth and areas where compaction appeared to be limiting. To identify compacted areas in this paddock plant height early in growth was assumed to have been reduced by compaction. Four replicates of each area were measured.
- Results in Table 1 indicate that yields differed between the two areas, and were 11 % higher in the assumed non-compacted areas.
- Soil density also differed but was higher in the area where there were large plants – and therefore assumed lower soil density areas - at both the 0-150mm and 150-300mm depth.
- This means that there were differences between the areas in soil density, but also that factors other than density affected yield at this site.

Table 1. Variations in yield and soil density between apparently compacted and non-compacted areas of a Manutuke paddock.

Paddock area	Grain yield (t/ha)	Soil density (kg/m^3) 0-150mm	Soil density (kg/m^3) 150-300mm
Large plants	16.3	1317	1563
Small plants	14.7	1283	1491
LSD*	1.44	34	52
Significance	0.04	0.05	0.009

* The LSD is the smallest difference between treatments that can be detected at a probability of 0.05.

Comparing areas within the paddock - Bulls

- Maize plant data was collected from areas within the paddock where compaction appeared to be non-limiting to growth and areas where compaction appeared to be limiting. This was again assumed to be related to plant height. Four replicates of each area were measured.
- Results in Table 2 indicate that yields were 77% higher in areas with no assumed compaction compared to areas with assumed soil compaction.
- Soil density was significantly higher in the areas of the paddocks where the smaller plants were, at both 0-150mm and 150-300mm depth.
- These data suggest that, in this paddock, high soil compaction is associated with decreased yields. However, other factors that may have reduced yield were not determined in this study.

Table 2. Variations in yield and soil density between apparently compacted and non-compacted areas of a Bulls paddock.

Paddock area	Grain yield (t/ha)	Soil density (kg/m^3) 0-150mm	Soil density (kg/m^3) 150-300mm
Large plants	9.2	1264	1410
Small plants	5.2	1329	1455
LSD*	1.94	33	44
Significance	0.007	0.001	0.04

* The LSD is the smallest difference between treatments that can be detected at a probability of 0.05.

Conventional and strip tillage effects on soil density - Ashcott

- Conventional tillage or strip tillage treatments were imposed at the Ashcott paddock and data on maize silage yield and soil density collected from 4 replicate plots in each cultivation treatment.
- Soil density was also measured within and between rows.
- Results in Table 3 indicate that silage yield did not vary with cultivation treatment.
- Cultivation did not affect the soil density in the top 150mm of the soil.
- However, cultivation decreased soil density in the 150-300mm depth by 5% compared with strip-tillage cultivation.
- Though the lower part of the soil profile had a lower soil density with conventional cultivation, it did not result in increased yields, suggesting that soil density levels in this paddock were not limiting to yield.

Table 3. Variations in yield and soil density with different cultivation treatments in and Ashcott paddock.

Paddock area	Silage yield (t/ha)	Soil density (kg/m^3) 0-150mm	Soil density (kg/m^3) 150-300mm
Conventional cultivation	22.3	1126	1236
Strip till cultivation	22.9	1122	1297
LSD*	3.3	61	55
Significance	0.27	0.91	0.03

* The LSD is the smallest difference between treatments that can be detected at a probability of 0.05.

- Analysis of coil compaction within and between rows showed that overall, soil density tended to be 7% lower within the rows, than between the rows in the 0-150mm depth. There was no difference in the 150-300mm depth (Table 4).
- There was no interaction between cultivation treatment and soil density within or between rows.

Table 4. Variation in soil density within and between rows in an Ashcott paddock.

Location	Soil density (kg/m^3) 0-150mm	Soil density (kg/m^3) 150-300mm
Within rows	1084	1291
Between rows	1165	1241
LSD*	61	55
Significance	0.01	0.08

* The LSD is the smallest difference between treatments that can be detected at a probability of 0.05.

Effect of ripping on soil density - Otane

- In this paddock ripped or non-ripped treatments were imposed to examine the effect on soil density.
- The whole paddock was strip-tilled prior to planting in maize. One part of the field was deep ripped to 350mm.
- Four replicate plots were used for data collection. Data included soil density measurements made in late December and maize grain yield immediately prior to harvest.
- In addition, soil density was measured within and between rows of the maize crop.

Effect of ripping on yield

- Results shown in Table 5 indicate that ripping did not affect maize grain yield.

Effect of ripping on soil density

- Ripping did not significantly change soil density in the 0-150mm depth, either between or in the rows.
- Ripping significantly reduced soil density at the 150-300mm depth, by 5% compared to not ripping.
- Though the 150-300mm depth of the soil profile had a lower soil density with ripping, this did not result in increased yields. This result is similar to results obtained from the Ashcott paddock, where decreasing density in the 150-300mm soil layer did not significantly improve yield.

Table 5. Variations in yield and soil density with ripping at Otane.

Paddock area	Grain yield (t/ha)	Soil density (kg/m^3) 0-150mm	Soil density (kg/m^3) 150-300mm
Ripped	8.2	1232	1274
Not Ripped	9.1	1247	1348
LSD*	1.1	19	32
Significance	0.07	0.11	0.001

* The LSD is the smallest difference between treatments that can be detected at a probability of 0.05.

- Ripping treatments had no effect on soil density levels within or between rows.
- However, there was an effect of depth on density within and between rows (Table 6). Density was lower within the row for the 0-150mm soil depth and higher within the row for the 150-300mm depth

Table 6. Variation in soil density within and between rows at Otane.

Location	Soil density (kg/m^3) 0-150mm	Soil density (kg/m^3) 150-300mm
Within rows	1181	1332
Between rows	1291	1292
LSD*	19	31
Significance	0.001	0.01

* The LSD is the smallest difference between treatments that can be detected at a probability of 0.05.

Conclusions

- The Troxler equipment is relatively expensive and requires a licensed operator.
- Testing the Troxler equipment for fitness-for-purpose showed:
    - The Troxler can give valid measures of soil density in cropping paddocks but must be calibrated for each soil type and depth.
    - A draft protocol for calibration purposes is presented.
    - Once calibrated, the Troxler offers the advantage of quickly collecting a large number of soil compaction measurements at different depths, without the cost of laborious physical soil core sampling.
- Field trials in maize paddocks showed:
    - Conventional cultivation and ripping tended to decrease soil density in the 150-300mm soil depth.
    - However, this decrease in density did not result in increased yields.
    - Only at one site (Bulls sand) was yield limited by high soil compaction.
    - Soil densities at Bulls were not significantly higher than at other sites.
    - At other sites, there was no effect of soil density on yield, but this may have been because factors other than soil density were limiting.
- Determining how density limits yields and under what conditions is necessary for an understanding of when mitigation options will be beneficial to yields.
- The use of a properly calibrated Troxler will allow the detailed measurements of soil density to help address this issue.

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LandWISE is a farmer dominated collective focused on economic and environmental sustainability. Formed 1999 to co-ordinate on-farm R&D and extension in vegetable and arable cropping, LandWISE was Incorporated 2003 as a society with charitable status.

LandWISE provides leadership and support to develop and promote sustainable crop production. Membership open to anyone who shares our objects.

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