The use of computer simulation as a decision making tool to improve machinery set-up, usage and performance.

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Abstract

Discrete element method (DEM) is a powerful computer simulation technique that can model soil and machinery interactions and predict aspects of soil manipulation and amendment incorporation within the soil profile. DEM can investigate different operation parameters without the need for expensive and time consuming field tests that can only be undertaken at certain times of the year. In this paper two different tools used for soil amelioration; namely the rotary spader and deep rippers with inclusion plate attached, have been investigated using DEM. The simulation results were also validated by performing a series of field tests. Result of the study showed that rotary spaders, commonly chosen to bury and mix soil amendments, resulted in large differences in the uniformity of mixing depending upon the machine set-up and operation. It was also found from the results of ripping with inclusion plate simulations that the amount of surface amendment material incorporated to deeper soil layers decreases with increasing forward speed and ripping depth. Results also showed that (further improvement is required in inclusion plate design for improved top-down material incorporation and the effect of surface amendment burial on crop response also needs further research

Key Words

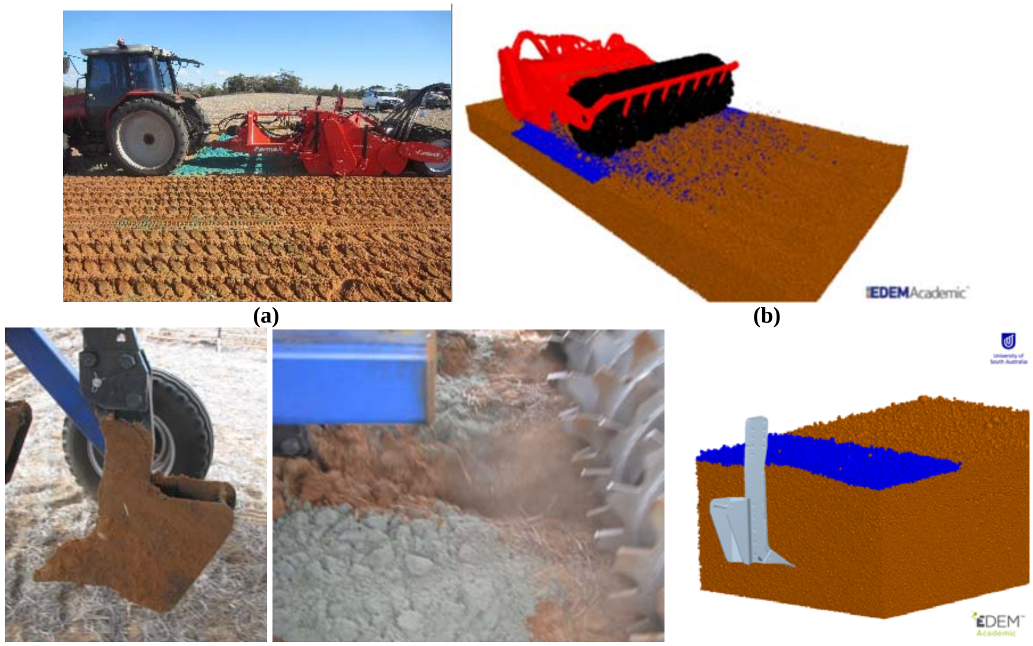
Discrete element method (DEM), deep ripping, inclusion plate, rotary spader

Introduction

Recent research shows that using rotary spaders can considerably improve biomass and grain yields from underperforming sandy soils by incorporating manure or organic matter, burying non-wetting top soil, removing compaction in shallow layers and breaking up and mixing in delved or spread clay (e.g. Roper et al. 2015). Although there is growing interest in spading underperforming sandy soils, its ability to incorporate surface applied amendments or to uniformly mix the whole soil profile is not fully understood or quantified. In order to incorporate the surface amendment materials to deeper soil layers, a new method of deep rippers with inclusion plates are also used. Using topsoil inclusion plates attached to deep ripper tines, can increase yields from deep sandy soils and lessen grain losses from dry and hot spring weather (Blackwell et al. 2016). The performance of these tillage implements is generally evaluated using field experiments. However, only a small number of implement settings and operating conditions are generally tested due to the resource intensive and costly procedures involved. A new approach by the research team at University of South Australia (UniSA) is to investigate the soil-tool interaction using a computer simulation technique known as discrete element method (DEM). DEM allows the interaction between machine and soil to be modelled, after a calibration process is implemented to reflect the field soil conditions. When applied to rotary spaders and deep rippers with inclusion plates, DEM simulations allow different operating conditions, such as forward speeds and operating depths to be investigated with the aim of understanding their impacts on layer mixing uniformity (for rotary spaders) and top-down material incorporation ability (for rippers with inclusion plates). The aim of this paper is to review the knowledge derived from DEM simulation results to date under these two case studies.

Methods

The movement of the topsoil mixing and topsoil inclusion was measured by tracking the soil movement during the tillage operation. To achieve this, a shallow recess was dug across the path of the tool and filled with blue coloured sand (Figures 1a and 1b). After the tillage operation, face pits were excavated across the direction of travel and a digital photo of each vertical slice was taken (Scanlan and Davies 2019), and digitally analysed to evaluate the extent of blue sand pixels within the images. Rotary spader experiments were performed in Ouyen/Victoria while inclusion plate trials were performed in Ouyen and Carwarp/Victoria. The field tests for spading were conducted using a 1.85m wide FARMAX spader whereas inclusion plate trials were performed using TILCO straight shank ripper tine with inclusion plate attached. The same processes were simulated via DEM (Figures 1c and 1d) under similar bulk soil conditions using the method developed by Ucgul et al. (2015). Comparing field experiments and DEM simulations, the coordinates of blue pixels and particles were able to be compared. The DEM simulations in this study were undertaken using EDEM^{TM} software.



(a) (b)

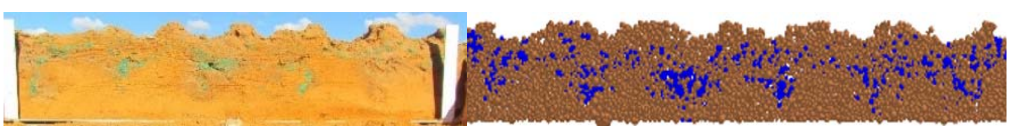
(c) (d) (e)

Figure 1. Top: rotary spading, (a) in field experiment and (b) simulated at full scale
Bottom: (c) ripper tine with inclusion plate, (d) in operation with blue sand, and (e) in simulation space

Results

Simulation of soil-rotary spader interaction

Both field tests and DEM simulations showed that spader blades gave distinct groupings of buried top layer particles (Figure 2). This effect occurs because of the cyclical operation dictated by the ‘bite length’ setting (bite length = distance at the soil surface separating two consecutive blades points of entry), which varies with forward speed, blade rotational speed and number of blades fitted along one row perimeter.



(a) (b)

Figure 2. Soil profiles after spading: (a) field test, (b) DEM simulation

A 3 dimensional assessment of the mixing quality was also possible with the DEM technique by dividing the soil bin volume into 50x50x50mm cells from which the proportion by volume of top layer particles in each cell was computed to develop colour coded spatial distribution maps of top layer particle concentrations. Six such 50mm thick layer maps can thus be produced to quantify the full spaded profile of 300 mm depth. A number of forward speeds were simulated, including 3, 5 and 7 km/h, and the visual results are displayed in the form of pixelated maps (1 pixel = 50 x 50 mm) shown in Figure 3. These single layer maps clearly show that more uniform topsoil mixing can be achieved at a slower forward speed, also minimising hot spot concentrations near the full working depth. The uniformity of topsoil incorporation by the spader when operating at 300 mm depth significantly reduces below 200 mm depth, suggesting a given spader blade design and positioning may have an optimal operating depth range to maximise uniformity of mixing. Increased speed (causing greater bite length) results in more heterogeneous topsoil mixing deeper in the profile (creating hot spots of concentration), while the mixing uniformity was typically found to be best in the middle third of the profile (100-200mm layer). All settings showed a small proportion of material remaining in the surface layer (smallest at the lowest speed), which is also observed in practice from spaded surfaces.

Higher uniformity of mixing in sandy soils is likely to be an advantage for incorporating products like clay and lime, which are considered to need a thorough blending to best achieve their aims. Combining a slow forward speed with reverse direction multi-pass spading is able to maximise the mixing uniformity (data not shown).

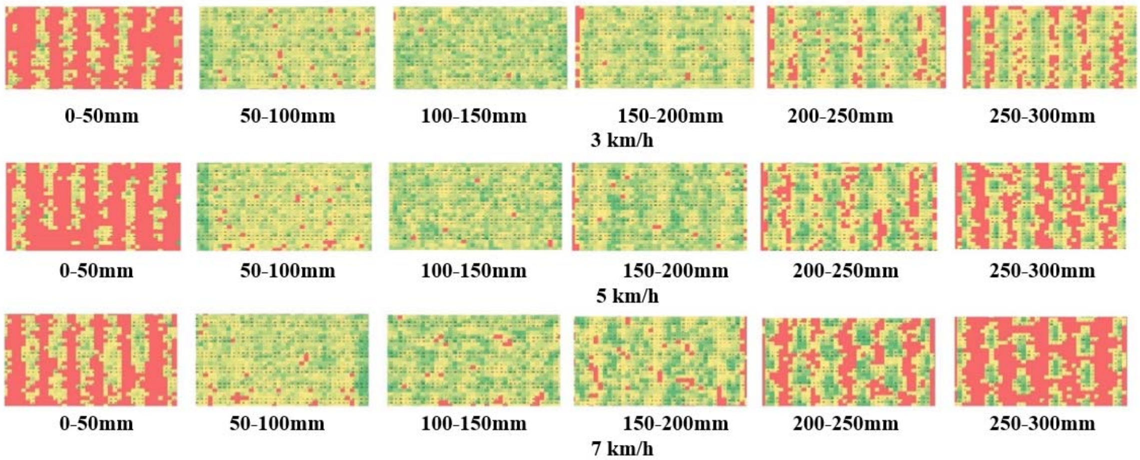


Figure 3 Spading at 300mm depth: Visual concentration patterns of topsoil particles in 50mm thick layers at 3 forward speeds (Note: the spader travelled from bottom to top of each top-view pixel map, direction green to yellow shades indicate high to low concentrations, with red representing zones of zero topsoil particles)

Conversely, distributed 'hot spots' of surface manures or organic matter amendments could be beneficial for crops, for more controlled dynamic responses Dedicated field research in for sandy soils is required to identify which soil amendments can benefit from more uniform spading in terms of crop response, and when less uniform (= lower cost) spading is adequate.

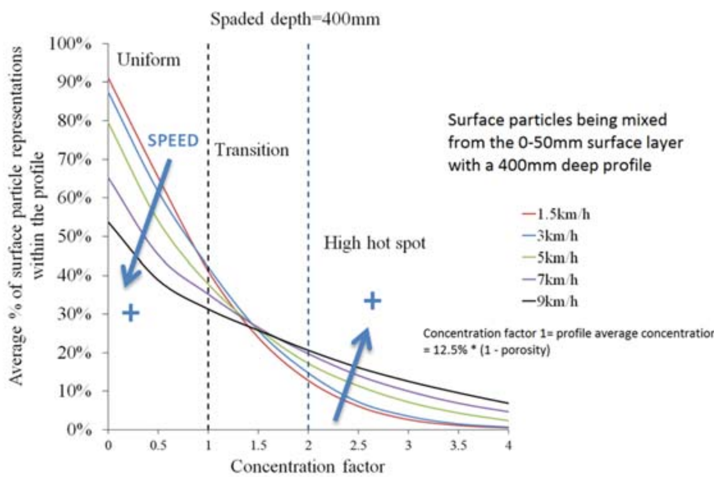


Figure 4 Impact of forward speed on the relationship between 'amendment distribution uniformity' and 'hot spot of increasing concentration' in a spaded soil profile at 400mm depths

The uniformity of mixing a surface layer amendment encompasses two aspects, namely i) uniformity of amendment representation in each basic cell in the simulated profile and ii) the frequency of hot-spots of various concentrations. Figure 4 highlights the relationships between these two parameters and their interaction with forward speed in the range of 1.5-9 km/h, based on simulation data at 400 mm spading depth. The modelling data show, as expected, a decay relationship between amendment distribution uniformity and frequency of hot spot of increasing concentration. As the forward speed increases, a rapid loss in amendment distribution uniformity can be seen, with a paralleling increase in the extent of amendment concentration within hot-spots. These data indicate the potential to identify optimum zones of operation for specific crop-amendment needs in constrained sandy soils.

Simulation of deep ripping with soil-inclusion plates

A similar process using blue coloured layer was followed to evaluate the performance of deep ripping with inclusion plates (Figure 5), showing good agreement between experimental observations and DEM simulations. Inclusion plates have three functional edges, namely, upper, lower and rear edges. Their position within the ripped furrow controls the extent and position of soil layer inclusion in the backfilling process.

The plate's upper edges are commonly set to 100-150mm below the initial soil surface. Field observations and DEM predictions (data not shown) show that shallower plates settings select soil layer inclusion from closer to the top layer which is important when aiming to include surface spread material (lime, organic matter) deep enough into the profile. Deeper upper edge settings reduce the extent of topsoil layer effective inclusion. Setting too shallow or even above the reference soil surface cancels any topsoil inclusion and restricts the furrow backfilling process to the rear and lower edges. The maximum inclusion depth is affected by the position of the plate lower edge which controls the extent of lower layer backfilling from behind the tine while the process of top-layer inclusion is occurring.

Research to date (Riethmuller and Parker 2019) shows the addition of inclusion plate significant increases the draft requirement of a ripper tine. DEM simulations suggest that positioning the plate lower edge closer to the bottom of the ripped furrow increases this draft penalty (data not shown) and field evaluation is under way to validate these aspects, including the impact of the bluntness of the inclusion plate forward faces.

The active zone of the inclusion plate upper edge varies with operating speed, and presumably with topsoil flowability. Faster speed restricts the available space for natural inclusion towards the rear of the plate. This effect is demonstrated by the shallower topsoil inclusion achieved at higher speeds (Figure 6). A wider plate would be expected to mitigate some of the negative impact of greater speed, but with a likely draft penalty.

DEM simulations to date suggest the design and performance of inclusion plates can be significantly optimised and tailored to achieve specific soil layer inclusion targets while minimising draft penalties. This process includes optimising these functional edges of the plate and the angles to mitigate their relative impacts on inclusion characteristics.

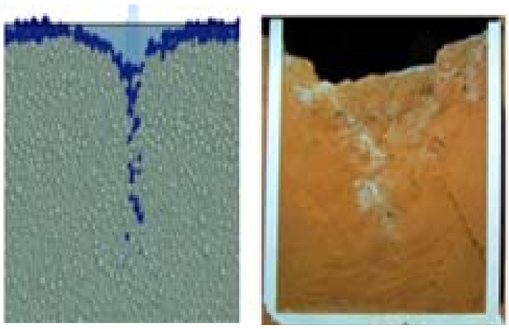


Figure 5. Example test vs. DEM comparison of blue coloured top soil inclusion while deep ripping at 3 km/h to 600mm depth and with an inclusion plate upper edge set at 170 mm below the original surface.

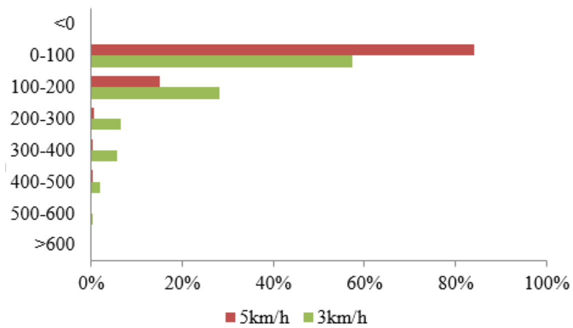


Figure 5. DEM predictions of the beneficial effect of slower speed on the proportions (%, v/v) of topsoil included in 100mm thick layers behind a deep ripper tine set at 600m depth with an inclusion plate upper edge set at 170 mm below the original surface

Conclusion

Computer simulation methods such as DEM can be used to understand the machine performance without performing costly and time consuming field tests. The information obtained from simulation results can be used to optimise soil-machine interactions and improve the reliability and quality of the soil manipulation operations. Future work will focus on investigating a wider range of soil tillage implements under different operating conditions, in different soil types and evaluating the crop yield responses to improved machine performance.

Acknowledgements

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References

Blackwell, P., Isbister, B., Riethmuller, G., Barrett-Lennard, E., Hall, D., Lemon, J., Hagan, J. and Ward, P., (2016). Deeper ripping and topsoil slotting to overcome subsoil compaction and other constraints more economically: way to go. Proceedings of the GRDC Grains Research Update, 29 Feb, 1 Mar 2016, Perth, WA.

Riethmuller, G. and Parker, W., (2019). Draft requirements of deep ripping with inclusion plates and speed. Proceedings of the GRDC Grains Research Update, 25-26 Feb 2019, Perth WA

Roper, M.M., Davies, S.L., Blackwell, P.S., Hall, D.J.M., Bakker, D.M., Jongepier, R., Ward, P.R. (2015). Management options for water-repellent soils in Australian dryland agriculture. Soil Research 53, 786–806.

Scanlan, C.A., and Davies, S.L. (2019) Soil mixing and redistribution by strategic deep tillage in a sandy soil. Soil and Tillage Research 185, 139-145.

Ucgul, M., Fielke, J.M. and Saunders, C., 2015. Three-dimensional discrete element modelling (DEM) of tillage: Accounting for soil cohesion and adhesion. Biosystems Engineering, 129, .298-306.