SOIL MIXING BY SPADING
FACT SHEET

NATIONAL
OCTOBER 2022

Understanding the process of soil profile mixing with rotary spaders

Research in the southern region over the past seven years has highlighted consistent crop benefits from 'mixing by spading' in a variety of deep sand and surface amendment contexts.

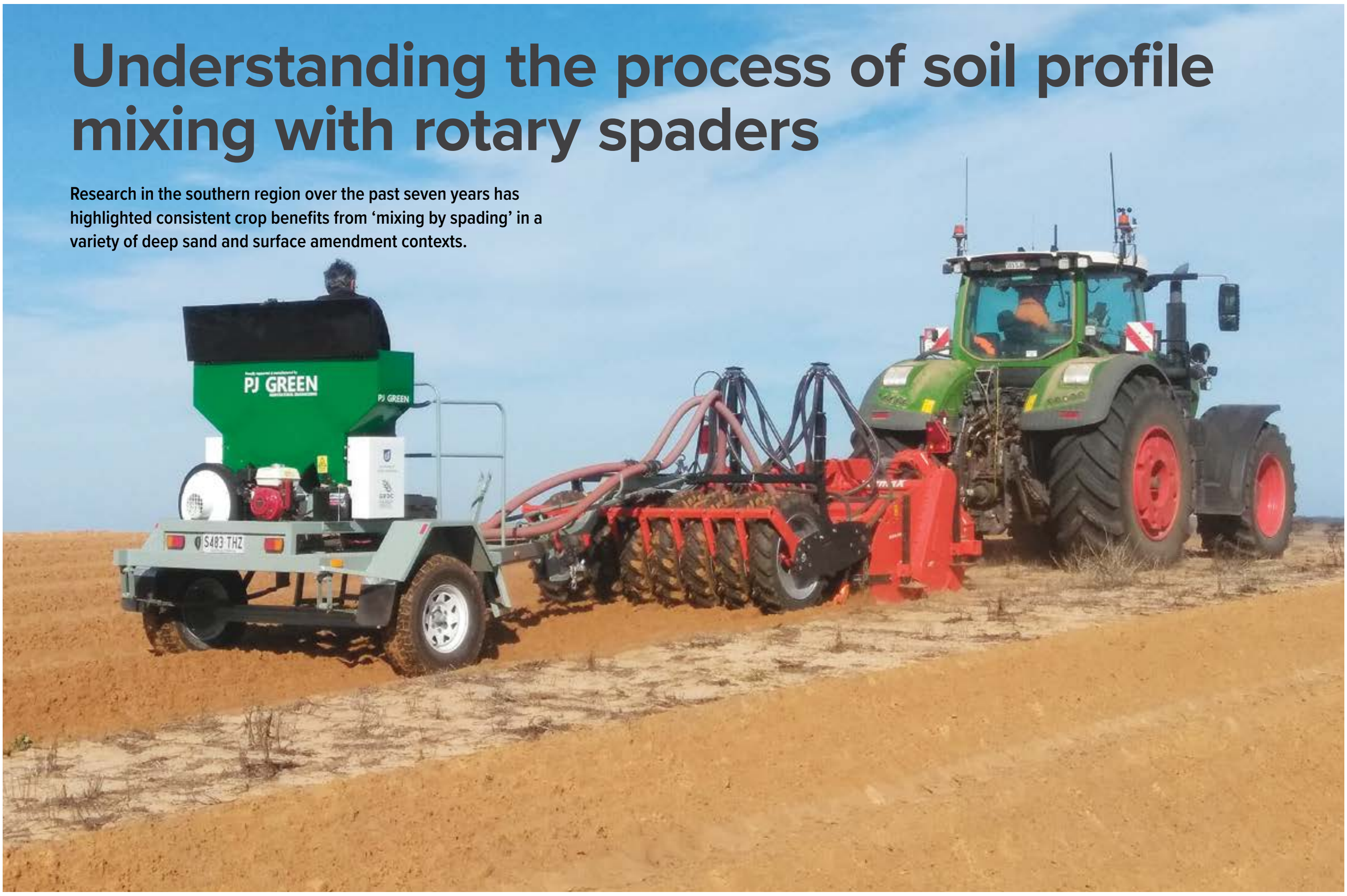


Photo: Jack Desbiolles

KEY POINTS

- Rotary spading is a cyclical process controlled by the extent of soil engagement between successive blades, the so-called 'bite length'
- Shorter bite length associated with slower ground speed significantly improves the uniformity of soil-amendment mixing, which can be further enhanced by a second spading pass, at best, in the opposite direction
- Topsoil layer mixing concentration typically peaks in the layer immediately below the surface and quickly reduces with depth
- A slow ground speed is required to more effectively mix topsoil into deep layers
- During spading, the redistribution of a deep soil layer up into the profile is less effective than the redistribution of an upper layer down into the profile. In both cases, the mixing uniformity is improved by a slower ground speed
- Spading after deep ripping or spading on a second pass requires 20 to 25 per cent less tractor engine power, whereby the saving in power take off (PTO) is partially mitigated by reduced self-propelling, increasing draught
- To achieve a high uniformity of mixing significantly increases spading costs per hectare (ha) while the returns via improved crop yields are not well documented and likely to vary depending on soil constraints and amendment contexts

Photo 1: a) One-pass 'spade and sow' operation timed into a moist soil profile is a safer sandy soil amelioration technique able to quickly re-establish ground cover while facing no soft soil-related trafficability issues and b) example of barley crop establishment in Victorian Mallee context following a successful 'spade and sow' operation.

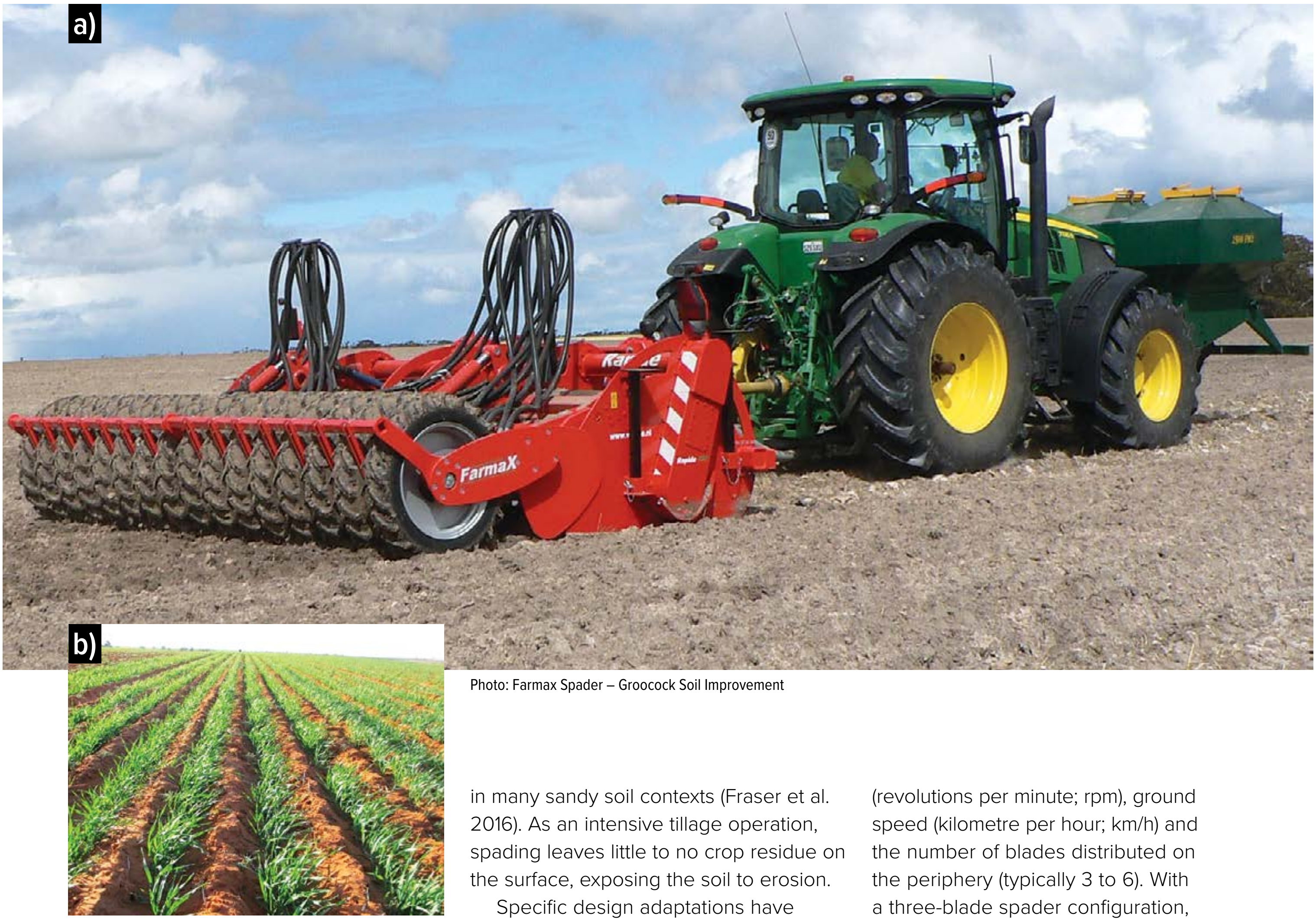


Photo: Farmax Spader – Groocock Soil Improvement

Photo: Jack Desbiolles

Introduction

This fact sheet reports on recent research aiming to understand the factors affecting the uniformity of soil profile mixing by rotary spading and the implications for paddock operations.

Rotary spaders were introduced from Europe to Australian grain growers in 2009 and have since transformed the ability to ameliorate sandy soil profiles down to a depth of 350 to 400 millimetres (mm) by mixing surface-applied amendments, loosening compacted layers and incorporating water-repellent and/or low pH topsoil. With its superior mixing ability compared with tyne or disc-based implements, rotary spading has been shown to produce significant and sustained grain yield improvements in many sandy soil contexts (Fraser et al. 2016). As an intensive tillage operation, spading leaves little to no crop residue on the surface, exposing the soil to erosion.

Specific design adaptations have gradually been made to reduce the risk of soil erosion and boost the adoptability of spading for ameliorating sandy soils (Desbiolles et al. 2019). These include large rear press-wheels leaving a consolidated profile with treaded furrows and one-pass 'spade and sow' techniques (Photo 1), which allow rapid crop establishment in soft post-amelioration seedbeds, therefore minimising the window for erosion.

Features of rotary spading

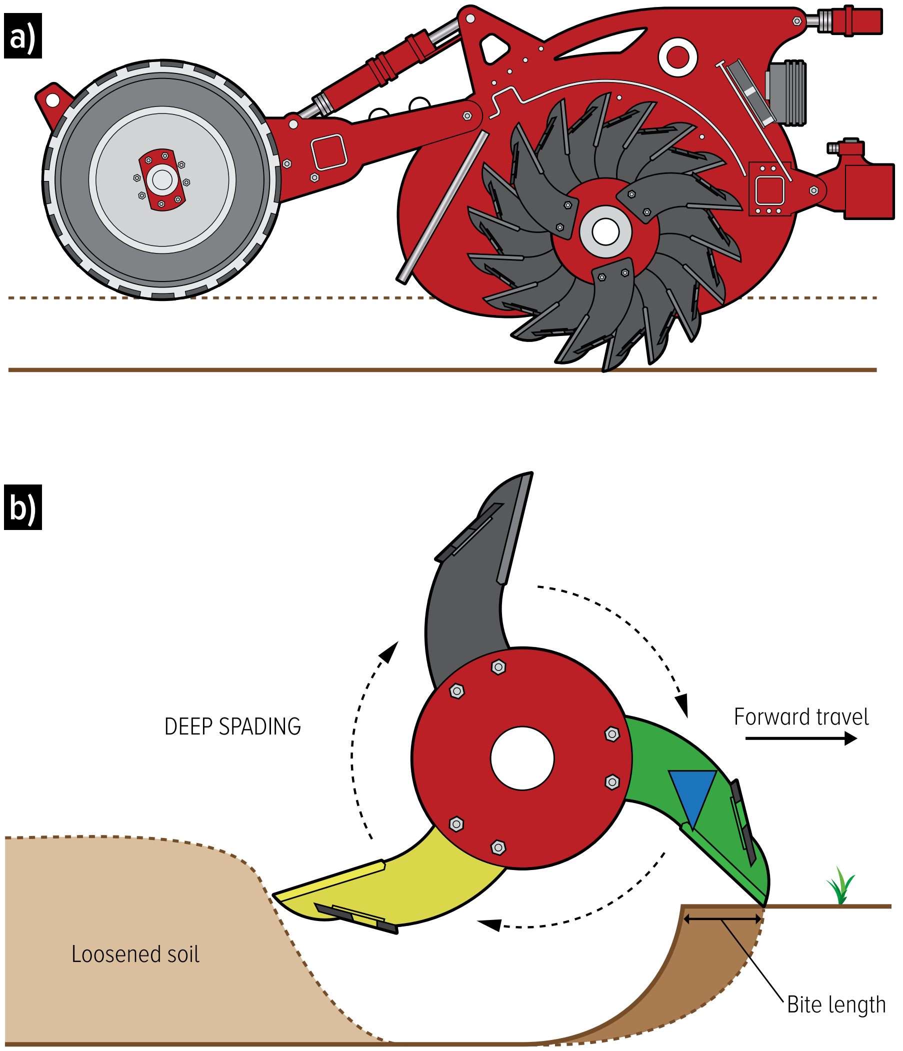
The spader is characterised by a cyclical loosening process centred around the 'bite length', this being the distance of forward travel between two successive blade actions, dictating the extent of soil engagement by each blade (Figure 1). The bite length is a function of the rotational speed (revolutions per minute; rpm), ground speed (kilometre per hour; km/h) and the number of blades distributed on the periphery (typically 3 to 6). With a three-blade spader configuration, the bite length is 350 to 400mm for an operating speed of 5.5 to 6km/h, but can be reduced or increased in direct proportion to ground speed.

Soil mixing process

The soil mixing uniformity is primarily controlled by the bite length, while operating depth and blade design also have some impact. Computer simulations based on Discrete Element Method (DEM) modelling and confirmed by paddock observations have revealed how a longer bite length leads to amendments being increasingly dispersed into hotspots rather than uniformly distributed along, across and down the spaded profile.

During the downward stroke of spading, the vertical wings of the blade slice through an undisturbed soil segment with little

Figure 1: Rotary spader staggered blade distribution across the rotor width (a) and fundamental bite length feature (b).



Source: UniSA

soil entrainment (that is, the blade makes a clean cut without dragging in much soil down the profile).

At the lowest point of the profile, the wings are almost in a horizontal position and are able to carry a scoop of soil towards the surface during the blade upward stroke. In this cyclical process, topsoil concentration occurs within the profile as shown by the bands of blue sand depicted in Figure 2. Decreasing the occurrence of concentrated hotspots or pockets underpins the process of improving the uniformity of mixing by spading.

Some of the soil (including topsoil) is carried out of the mixed profile by the blades and thrown onto the spader shield with a portion recirculating to the front (Figure 2a). These outward soil projections inside the spader shield and at the front of the spader can clearly be seen in paddock operations.

The full process of soil profile mixing can be analysed in computer simulations by tracking the movement of top, middle or bottom soil layers during spading. With this, we can assess the extent of amendment incorporation (for example, surface-applied lime or manure), soil constraint dilution (for example, water-repellent top layer or acidic sublayer) or beneficial layer distribution (for example, loamy or clay layer in sandy duplex soil).

Depth distribution

A primary objective of spading is to mix the surface layer, often with surface-applied amendments, into a deficient profile. This top-down mixing process often carries an expectation to 'bury at depth', for example resistant weed seeds or surface water repellence. Figure 3 depicts a typical distribution of top layer particles with depth, showing a peak (or bulge) of greater concentration within the soil profile just below the surface layer. The data consistently show that some surface particles remain within the top layer post-spading, which highlights the dilution by mixing – rather than by full burial – features of the spading process.

This top-down mixing process occurs simultaneously with the relocation and mixing of other layers within the profile, including a bottom-up mixing process (see further down).

In water-repellent sands, the spading process dilutes the high repellence surface layers by taking water-repellent soil down into the profile and bringing up wettable deeper layers.

Impact of speed

Figure 3 also illustrates the simulated redistribution of the topsoil (0 to 50mm) after spading various layers down to 300mm depth. Perfectly uniform mixing should result in about 17 per cent of the topsoil in each of the six layers, as indicated by the dotted line. Spading at 3km/h comes close to this ideal, with greater percentages (6 per cent extra) of topsoil in the 50 to 100mm layer and smaller amounts (3 to 8 per cent less) at depth. The bulge layer feature in the 50 to 100mm depth is greatest at 9km/h, indicating the need to maintain a slow forward speed (that is, a short bite length) to achieve a more even average distribution with depth. In some cases, slower spading can displace the bulge layer to lower depths (Figure 5), increasing the average depth of incorporation.

Spading depth

Depth of spading helps incorporate the topsoil into deeper layers, but this is most effective when operating at a slower speed (see Figure 4). The spaded deeper layers contain the least topsoil, with particles isolated into more discrete spots.

This reduction with depth is most pronounced at higher speed. Spading deeper rather than shallower concentrates a greater quantity of surface particles in the bulge layer relative to the expected average (for example, twice as much at 9km/h, see Figure 4), while the depth of the bulge layer within the profile remains unchanged, that is, just below the surface layer.

Bottom-up mixing

Another objective of spading may be to simultaneously achieve a bottom-up mixing outcome, for example the mixing of higher clay content sublayers into a water-repellent sandy surface soil.

In this context, Figure 5 shows the average redistribution of the 200 to 250mm deep layer up into the profile following spading to 300mm depth. The graph shows that the bottom-up mixing process is less effective than the top-down mixing of the surface layer in Figure 3. In this simulation, 37 to 68 per cent of particles (maximum at 9km/h) were left in the initial layer with some displaced to the layer below. This is due to the impact of a very localised interaction by the blade within deeper soil layers.

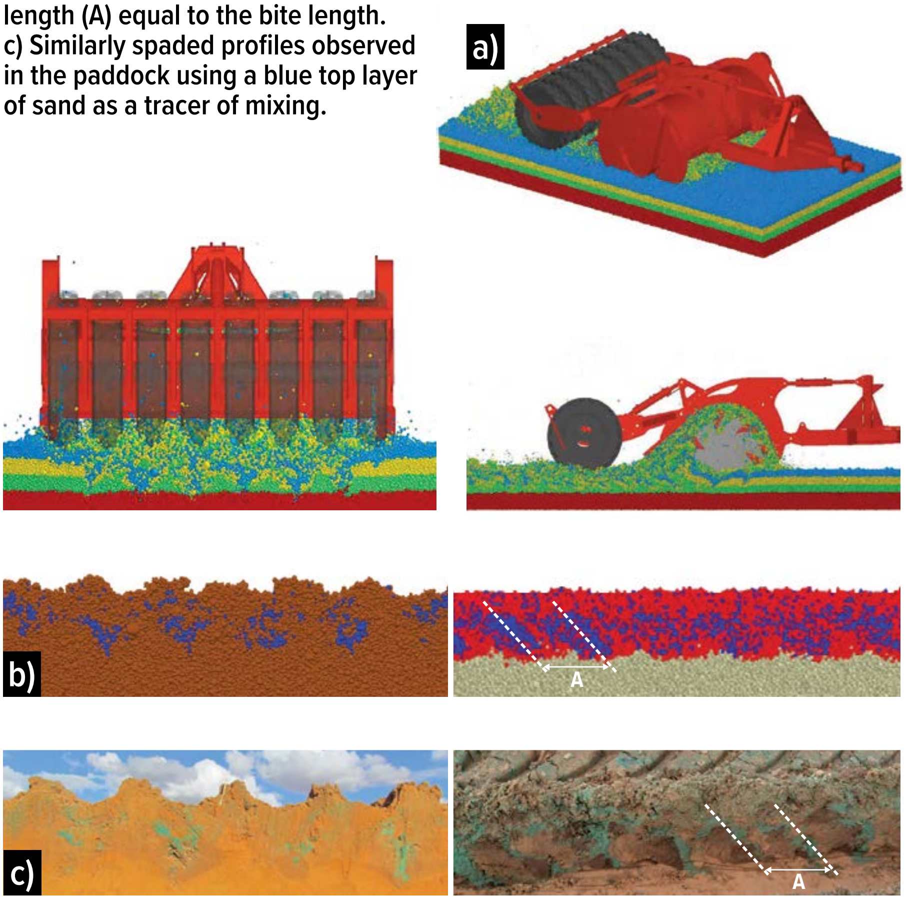
The spading simulation at 300mm depth shows some ability to bring up some soil (13 to 20 per cent, minimum at the high speed) from the 200 to 250mm layer to the top 100mm layer where it may be further mixed by secondary tillage including during crop seeding.

The ability to lift soil from the 250 to 300mm layer would be significantly less. This suggests the need to spade to a depth beyond the layer of interest to be able to bring enough of it up into the topsoil.

Spader design

Figure 6 shows the difference in simulated topsoil distribution with depth between two contrasting spader designs. While both designs display a similar top-layer distribution pattern with depth, the Design 2 spader (with sets of six small left and right-hand blades spread around the rotor) was slightly better than Design 1 (with sets of three full blades spread around the rotor) at incorporating top layer particles deeper into the profile

Figure 2: a) Isometric, rear and side views from a computer simulation of a rotary spader operating at 300mm depth and 9km/h through a multi-layer sandy soil profile. b) Simulated mixing of the top layer (blue particles) into the profile, across the spaded width (left) and along the travel direction (right). The mixing outcome shows pockets of concentrated blue particles in a cyclical pattern repeated at an amplitude length (A) equal to the bite length. c) Similarly spaded profiles observed in the paddock using a blue top layer of sand as a tracer of mixing.



Source: UniSA

Figure 3: Simulated pattern of topsoil (0-50mm layer) particle distribution after spading to 300mm depth showing a peak in the layer immediately below surface (% indicate the redistributed proportions of the original 100 per cent surface layer). The contrast over three speeds shows the peak is much less pronounced at slow speed, indicating a more uniform distribution with depth. Red circling marks the tracked original layer of interest.

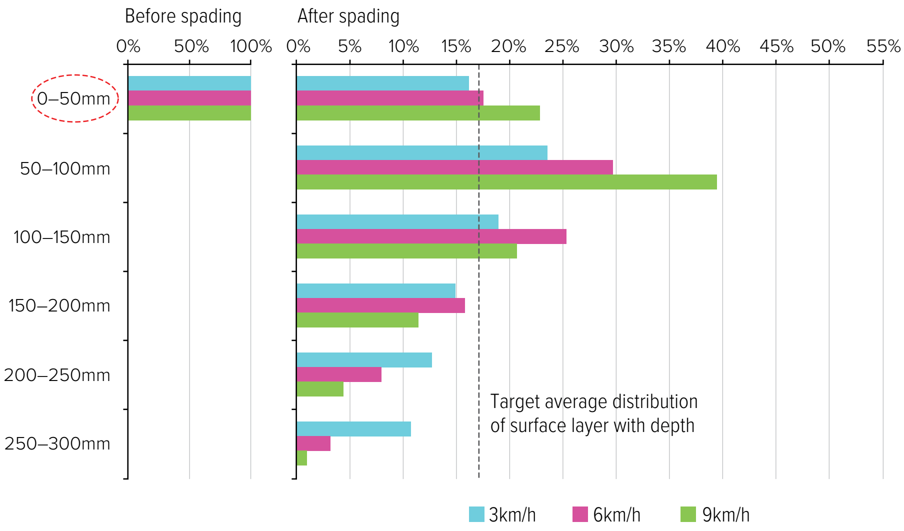
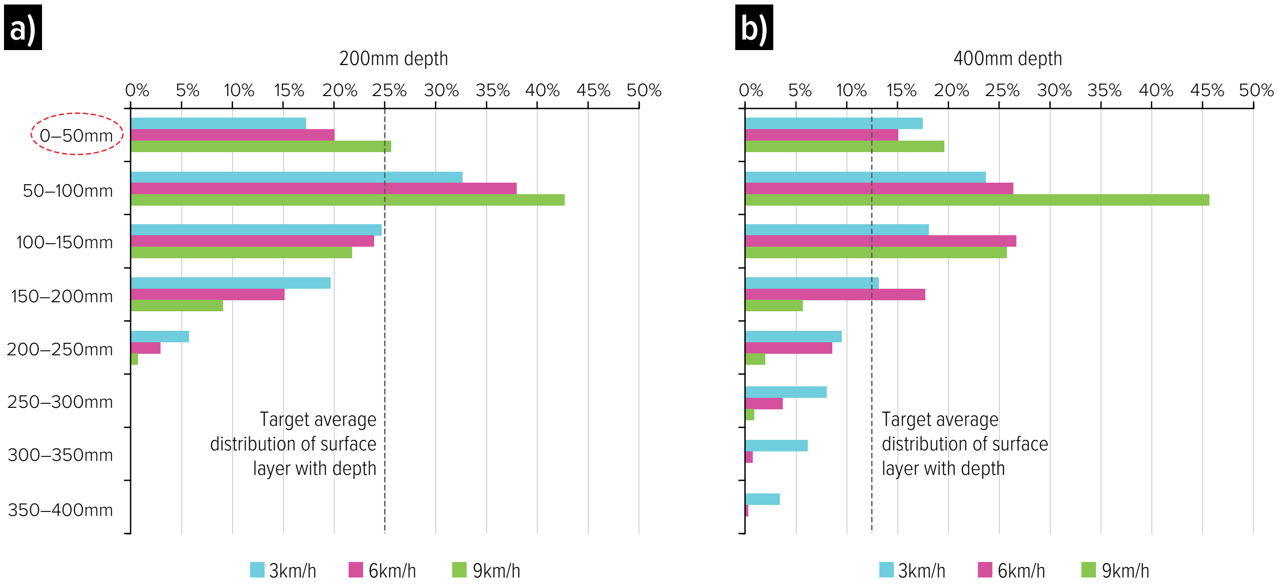


Figure 4: Simulated effect of spading depth (a) 200mm and (b) 400mm on topsoil (0–50mm layer) particle distribution down the profile (% indicates the redistributed proportions of the original 100 per cent surface layer). Red circling marks the tracked original layer of interest.



at slower speeds, and also displacing the bulge layer of concentration deeper into the profile (from 50 to 100mm at 9km/h to 150 to 200mm at 3km/h).

These differences between designs were negligible at the higher speed. Further simulation work will aim to look at the impact of the different blade configurations on relative power requirements.

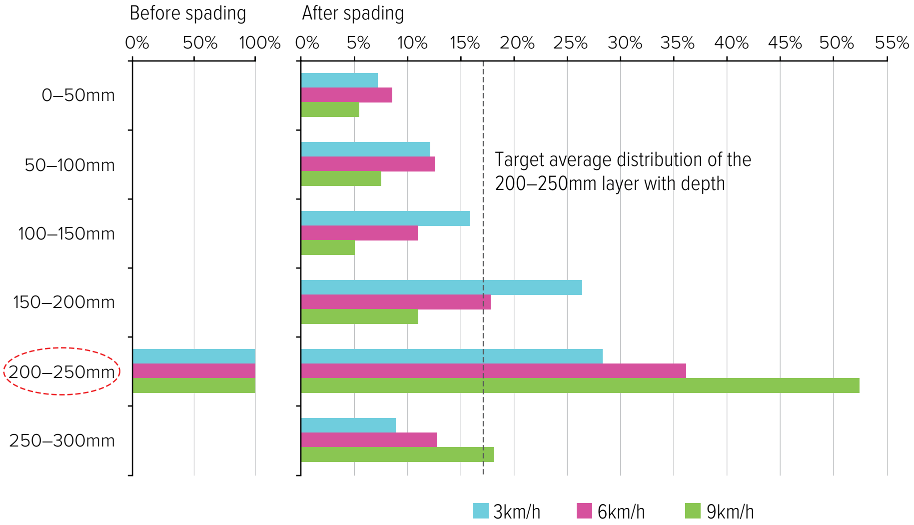
Soil profile moisture

Spading wet soil with some level of soil particle cohesion increases entrainment (or dragging down) by the blade relative to spading dry soil, which tends to increase the burial of the surface layer to depth (data not presented). It seems that increased clustering of particles occurs when spading moist soil compared with dry soil, which may reduce the mixing uniformity within the profile. It may be more important to spade slowly in wet conditions to achieve similar mixing uniformity. More work is required to quantify this effect.

Uniformity of mixing within layers

While Figures 3 to 6 show only the average concentrations by layer, Figure 7 displays the variability within each layer of a spaded profile, in a 2D top view pixelated format.

Figure 5: Simulated mixing outcomes of the 200 to 250mm deep layer particles within a 300mm deep spaded profile at three contrasting speeds (% indicates the redistributed proportions of the original 100 per cent of the 200 to 250mm layer). Red circling marks the tracked original layer of interest.

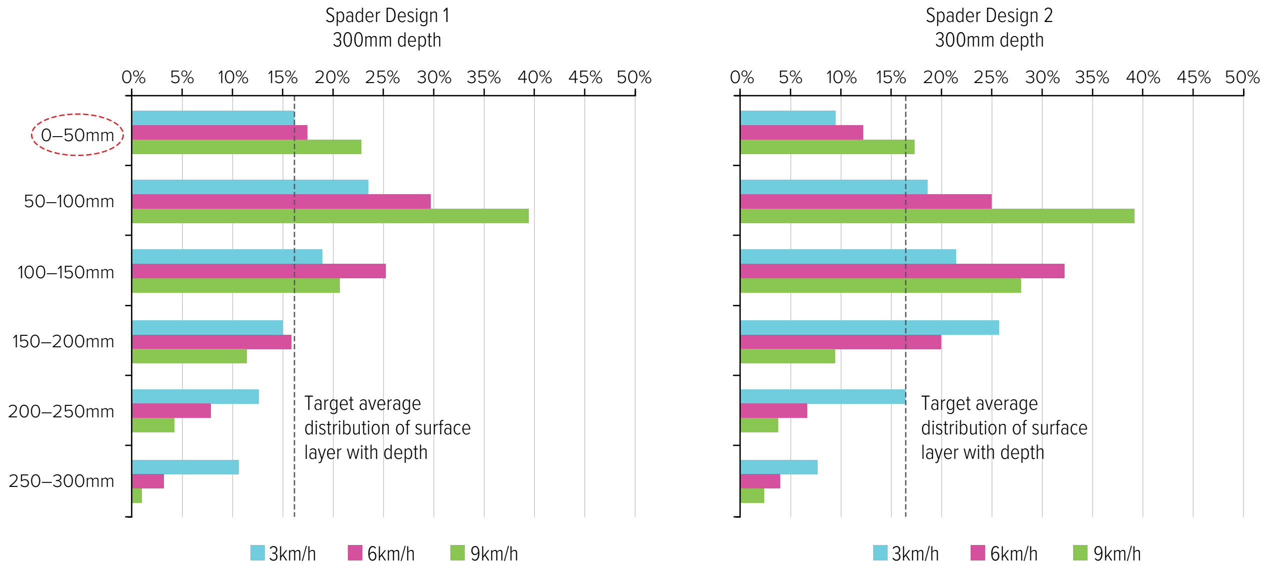


The figure contrasts the redistribution within the spaded profile of the surface layer (0 to 50mm) and of a 200 to 250mm deep layer at 3 and 9km/h speeds. Also shown is the spading direction, which reveals the cyclical footprint of the spader blades at their respective bite length and spacing across the width.

The pixelated layer by layer display provides a clear appreciation of the 3D pattern of particle mixing, in particular:

1 **The visualisation of the bulge layer of surface particles peaking in the layer immediately below (as shown in Figure 3), and the localised release pattern in the layers below into distinct hotspots, decreasing in size with depth.**

Figure 6: Simulated effects of spader design on the top-layer distribution with depth following spading to 300mm depth at three speeds (% scale indicates the redistributed proportions of the original 100 per cent surface 0 to 50mm layer). Note: Design 1 uses sets of three large blades around the rotor and Design 2 uses sets of 3+3 left-hand and right-hand smaller blades around the rotor. Red circling marks the tracked original layer of interest.



2 **The visualisation of the bulge concentration of deep layer particles remaining in their original layer after spading (as shown in Figure 5), showing portions of the 200 to 250mm deep soil particles scooped by each blade and released across layers in a localised fashion under high spading speed, while much better distribution at low speed is shown, despite some banding contrasts remaining in the original layer, and fading above it.**

3 **In both cases, a similar banded contrast displayed at depth under low-speed spading, either from uncaptured sections of the original deeper layer or from hotspot features following the entrainment of surface layer particles down the profile.**

4 **The visual differences in surface soil particles left in the 0 to 50mm layer after spading, which is an indicator of unincorporated surface amendment, unburied surface weed seeds, or remaining surface water repellence, depending on the context of spading.**

Multi-pass operation

Multi-pass spading is an effective way of increasing the mixing uniformity, but the overall work rate is halved and the cost of spading per ha (10,000m^2) nearly doubles. For the best impact on mixing uniformity, the second pass spading should be conducted in the opposite direction and, where possible, offset by half the blade spacing.

Although crop responses to high uniformity spading are not well documented, recent research in SA suggests significant extra benefits may arise under high uniformity spading of lime into an acidic sandy soil (Ucgul et al. 2022), while crop responses may differ in other contexts such as spading chicken litter into a nutrient-deficient sand. More work is required to understand where the crop is most likely to benefit from high quality (and more costly) soil/amendment mixing when ameliorating sandy soil profiles.

Power requirements

Research conducted in SA has shown that the spader power take off (PTO) torque requirement is approximately proportional to forward speed or bite length. Conversely, the spader draught decreases with greater bite length, as the spader more effectively pushes itself along at faster forward speed. A zero net draught was found at 6km/h when spading at 350mm depth, with the spader effectively pushing the tractor at faster speeds.

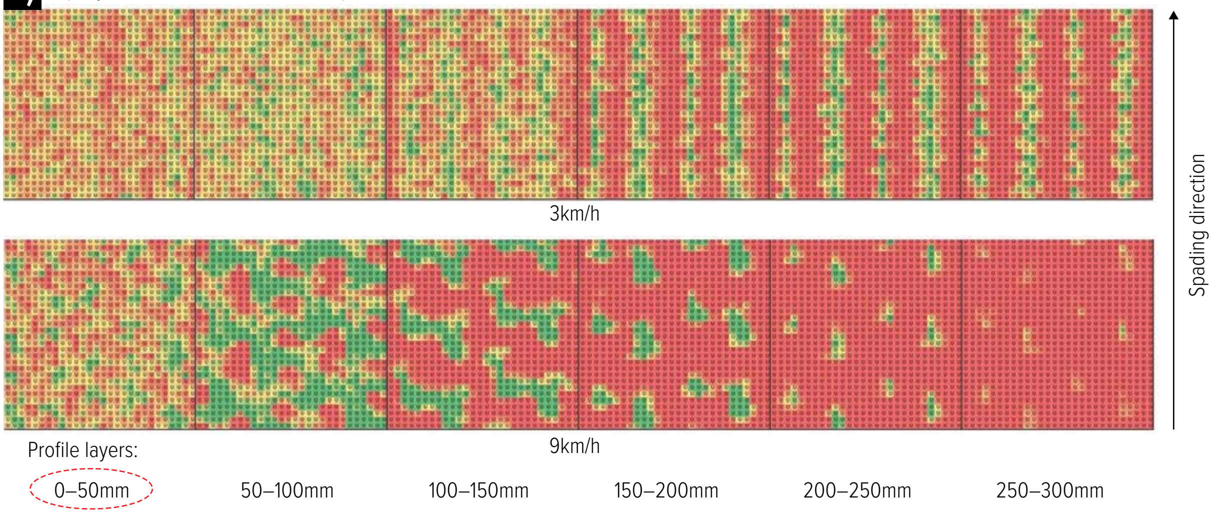
This self-propelling effect is more effective at shallower depths whereby the spader more actively pushes the tractor. The above features help explain how the overall tractor engine power requirement may be affected in operation.

In field measurements conducted in a sandy soil context in Upper South East SA (Ucgul et al. 2022) showed that the engine power increased – after a threefold rise in speed (from 3 to 9km/h) – by 99 per cent and 71 per cent at 250mm and 350mm spading depth, respectively.

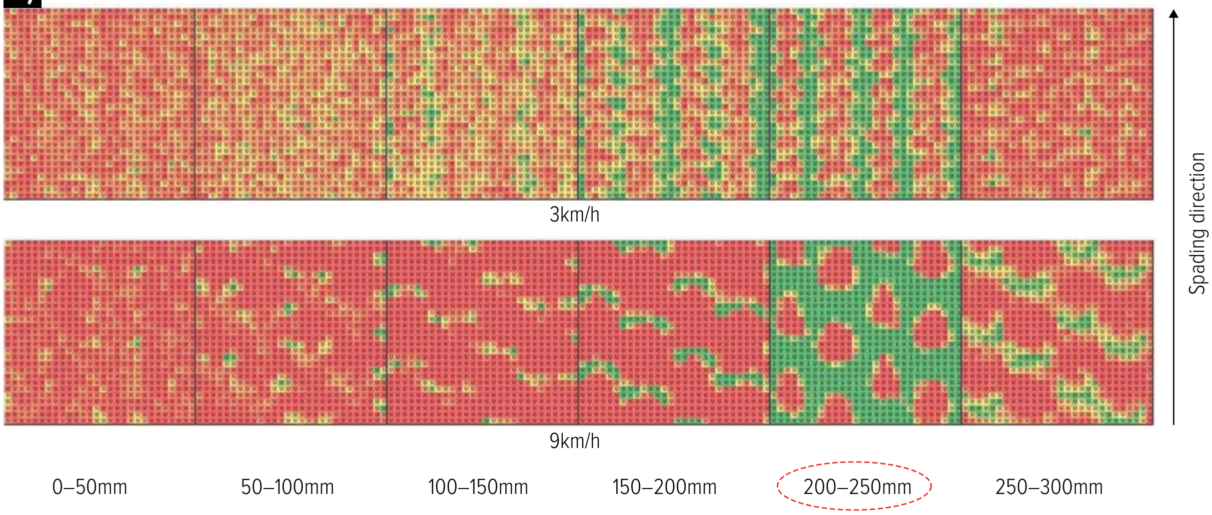
This makes fast spading more economical per ha, particularly when spading deeper, but as shown in the sections above achieves a much lower mixing uniformity. In contrast, when spading 40 per cent deeper from 250 to 350mm, a similar engine power increase of 95 per cent and 68 per cent was measured at 3 and 9km/h, respectively, showing how the cost of deeper spading is much more significant but, in relative

Figure 7: Top view simulation (50x50mm pixel resolution) of the distribution of 0 to 50mm topsoil particles (a) or 200 to 250mm deep layer particles (b), within individual layers of a 300mm deep spaded soil profile, at two speeds (colour coding: light yellow to dark green indicates increasing concentration of tracked particles from the layer of interest, red colour indicates all other soil particles from layers outside the layers of interest). Each layer in top view represents an area of 1.4m wide x 1.5m travel. Red circling marks the tracked original layer of interest.

a) Top layer distribution down into the profile



b) Lower layer distribution up into the profile



terms, is minimised at faster speeds.

In similar paddock trials, spading into a deep-ripped profile reduced the tractor engine requirements by 22 per cent on average relative to unripped soil, with maximum power savings obtained under higher spading speed. Similarly, the power requirements of a second pass spading were 23 per cent lower on average than an equivalent first-pass spading, across a range of depths and speeds, with the best reductions occurring at high speeds.

In both cases, the power reduction benefits of spading into a pre-loosened soil integrate the effects of reduced PTO torque, of increased draught from reduced 'self-propelling', and of slightly greater operating depth due to sinkage compared with spading into the undisturbed profile.

Overall, these results highlight that a majority of power is expended from purely moving large volumes of soil during spading, whether from a pre-loosened or an undisturbed base.

Commercial spaders are now available with optional pre-ripping tynes (Photo 3). Such combination implements offer an innovative basis to address multiple constraints within a deep profile, such as via deep loosening, sub-layer delving and/or topsoil inclusion prior to mixing of the upper profile and surface packing. One-pass 'rip, spade and sow' operations into moist profiles provide low-risk soil amelioration solutions.

Photo: Farmax Spader – Groocock Soil Improvement

Photo: Imants Spading Western Australia

Photo 3: Combining deep ripping with spading in one pass is now commercially available and allows complementary remedies to be applied towards multiple constraints within a deeper profile.

MORE INFORMATION

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