SOIL MIXING BY SPADING
FACT SHEET

INTERIM VERSION
(AUG-2022)

Understanding the process of soil profile mixing with rotary spaders

Key points

- Rotary spading is a cyclical process controlled by the extent of soil engagement between successive blades, the so called the 'bite length'.
- Shorter bite length associated with slower ground speed significantly improves the uniformity of soil-amendment mixing, which can be further improved by a second spading pass in the opposite direction.
- Topsoil layer mixing concentration typically peaks in the layer immediately below the surface and quickly reduces with depth.
- A slow spading ground speed is required to 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 lower speeds.
- Spading after deep ripping or spading on a second pass requires 20-25% less tractor engine power, whereby the saving in PTO power is partially mitigated by a reduced self-propelling, increasing draught.
- High uniformity of mixing significantly increases spading costs per ha and the returns via improved crop yields are not well documented, with these likely to vary across soil constraints and amendment contexts.

Research in the southern region over the last 7 years has highlighted consistent crop benefits from 'mixing by spading' in a variety of deep sand and surface amendment contexts *(Image Jack Desbiolles)*

Introduction

This factsheet reports on recent research aiming to understand the factors affecting the uniformity of soil profile mixing by rotary spading and the implications for field 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 up to 350mm by mixing surface applied amendments, loosening compacted layers and incorporating water repellent and/ or low pH topsoil. With its superior mixing ability over tine or disc-based implements, rotary spading has been shown to produce significant and sustained grain yield responses in many sandy soil contexts (Fraser et al. 2016). Like most tillage operations, spading leaves little to no crop residues on the surface, leaving the soil prone 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 (e.g. Photo 1) which allow rapid crop establishment in soft post-amelioration seedbeds minimising the window for erosion.

Photo 1: Left: 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 *(Image courtesy of Farmax Spader - Groocock Soil Improvement)* ; ***Right: example barley crop establishment in Vic Mallee context following a successful 'spade and sow 'operation*** *(Images Jack Desbiolles)*

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 (rpm), ground speed (km/h), and the number of blades distributed on the periphery (typically 3 to 6). With a three blade spader configuration, the bite length commonly sits at 350-400mm for an operating speed of 5.5-6 km/h, but can be reduced or increased in direct proportion to ground speed.

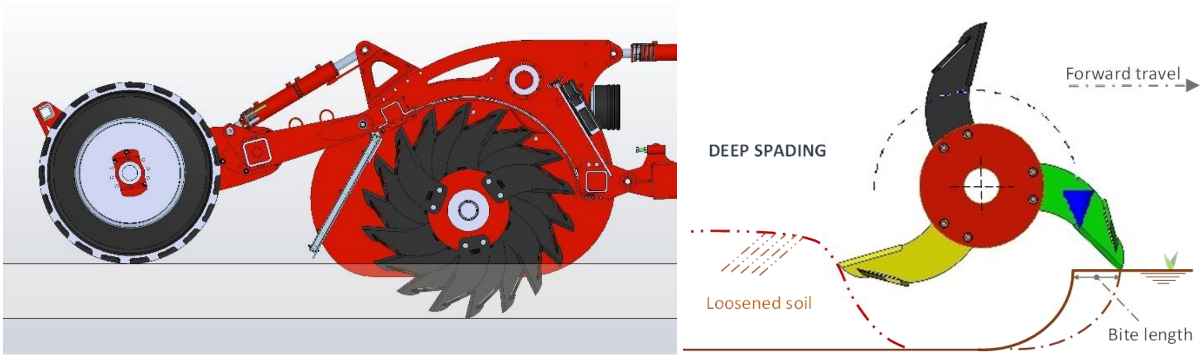

Figure 1: Rotary spader staggered blade distribution (left) and bite length feature (right)
(source UniSA)

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 field observations have revealed how a longer bite length leads to amendments being increasingly concentrated into 'hot-spots' rather than uniformly distributed along, across and down the spaded profile.

During the downward stroke of spading, the blade vertical wings slice through an undisturbed soil segment with little soil entrainment i.e. the blade makes a clean cut without dragging in much soil with it down the profile. By the lowest point into the profile, wings have turned close to a horizontal direction and are able to carry a scoop of unmodified soil towards the surface during the blade upward stroke. In this process, forward and rear sections of soil layers (including topsoil) are deposited by the blade within the profile as it continues rotating upward. A process of concentration occurs whereby the topsoil falling off the wing upper edge of a preceding blade is completed by more topsoil falling over the wing lower edge of the following blade. The resulting bands of blue sand depicted on the longitudinal spaded profile (Figure 2, bottom) are the visual traces left by this process. Decreasing the occurrence of concentrated 'hot-spots' or pockets underpins the process of improving mixing by the spader.

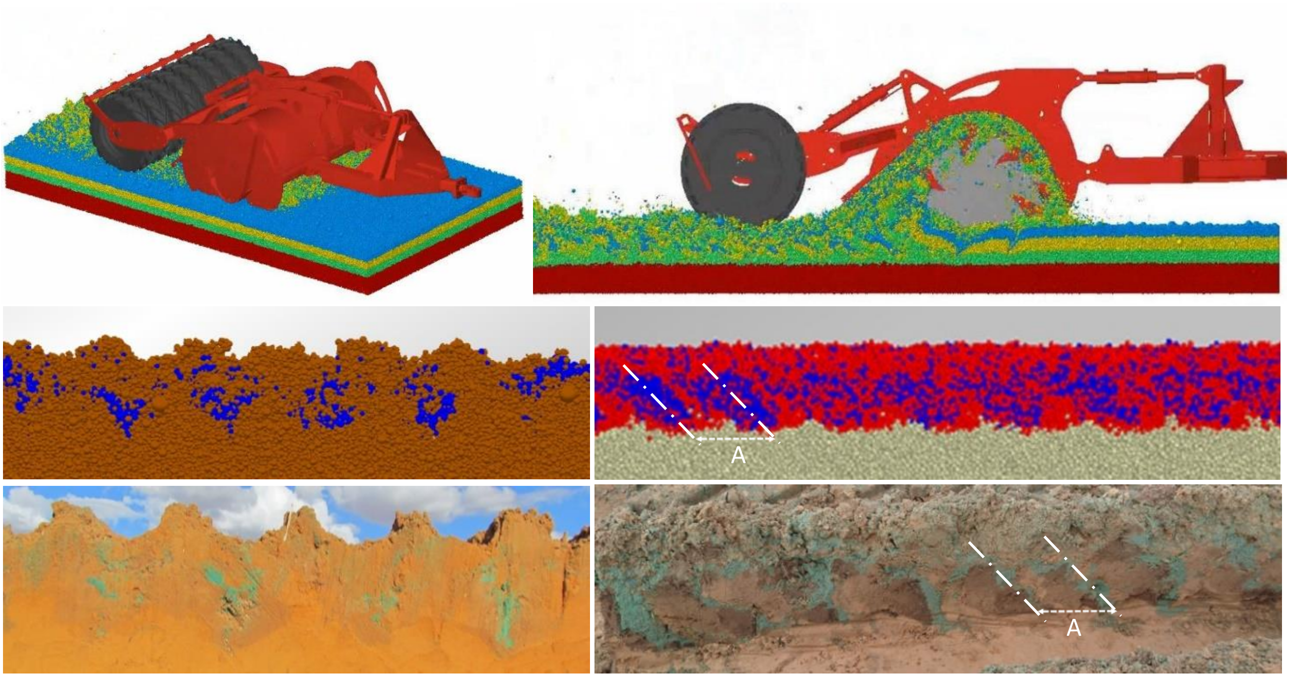

Figure 2: <u>Top</u>: Computer simulation of a rotary spader operating at 300mm depth and 9 km/h through a multi-layer sandy soil profile. <u>Centre</u>: Simulated mixing of top-layer (blue colour particles) into the profile, across the spaded width (left) and along the travel direction (right). The mixing outcome shows pockets of concentrated blue particles in a cyclical pattern repeated at an amplitude length (A) equal to the bite length. <u>Bottom</u>: Similarly spaded profiles observed in the field using a blue coloured top layer of sand as a tracer of mixing. *(source UniSA)*

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 re-circulating to the front (See Figure 2, top-right). These outward soil projections inside the spader shield and at the front of the spader can clearly be seen in field 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, the extent of amendment incorporation (e.g. surface-applied lime or manure), soil constraint dilution (e.g. water repellent top-layer or acidic sublayer) or beneficial layer distribution (e.g. loamy or clay layer in sandy duplex soil) can be assessed.

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) within the soil profile just below the surface layer. The data consistently shows that some surface particles always remain within the top layer post-spading, which highlights the dilution by mixing - rather than 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 repellent soil down into the profile and bringing up wettable deeper layers instead.

Impact of speed

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

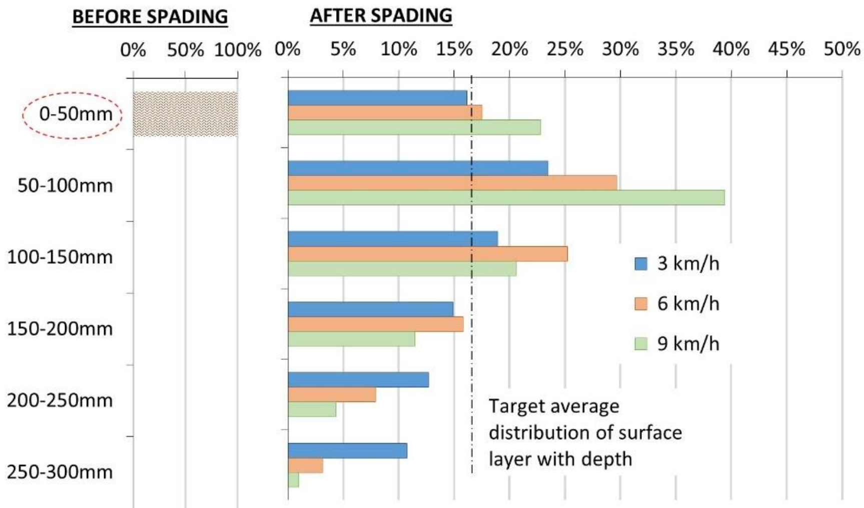

Figure 3: Simulated pattern of top-layer (0-50mm) particle distribution after spading to 300mm depth showing a peak in the layer immediately below surface (% indicate the re-distributed proportions of the original 100% surface layer). The contrast over three speeds shows the peak is much less pronounced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

Spading depth

Increasing the depth of spading helps incorporate the topsoil into deeper layers, but most effectively when operating at a slower speed (see Figure 4). The spaded deeper layers always contain the least topsoil, with particles isolated into more and more discrete spots. This reduction with depth is most pronounced at higher speed. Spading deeper rather than shallower concentrates a greater quantity top-layer particles in the bulge relative to the expected average (for example, twice as much at 9 km/h, see Figure 4), while the depth position of the bulge within the profile remains unchanged, that is, in the layer just below the topsoil layer.

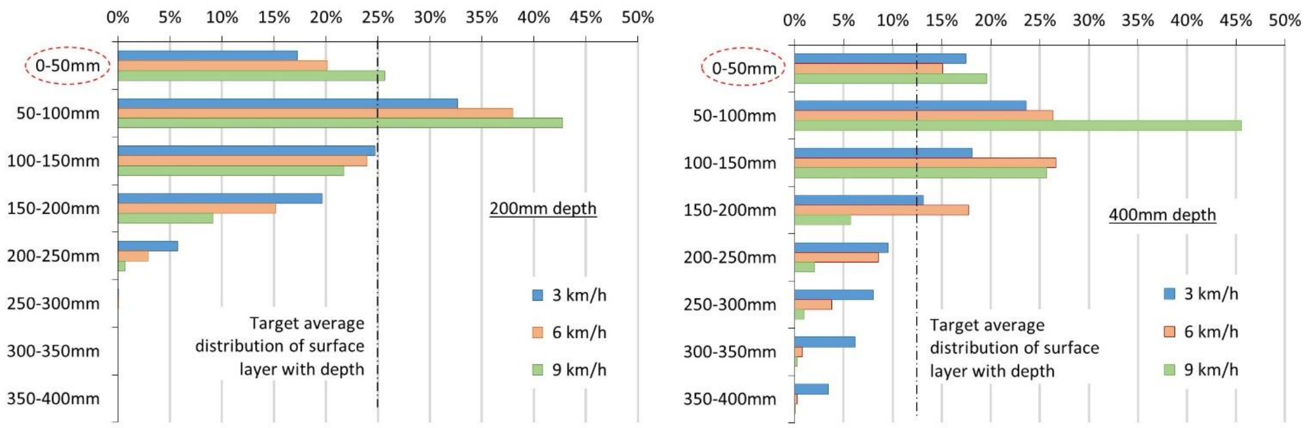

Figure 4: Simulated effect of spading depth (left: 200mm, right: 400mm) on topsoil particle distribution down the profile (% indicate the re-distributed proportions of the original 100% surface layer).

‘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 sub-layers into a water repellent sandy surface soil. In this context, Figure 5 shows the average re-distribution of the 200-250mm deep layer up into the profile following a spading operation to 300mm depth. The graph shows that the ‘bottom-up’ mixing process is less effective than the ‘top-down’ mixing of the surface layer depicted in Figure 3. In this simulation, 37-68% of particles (maximum at 9 km/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.

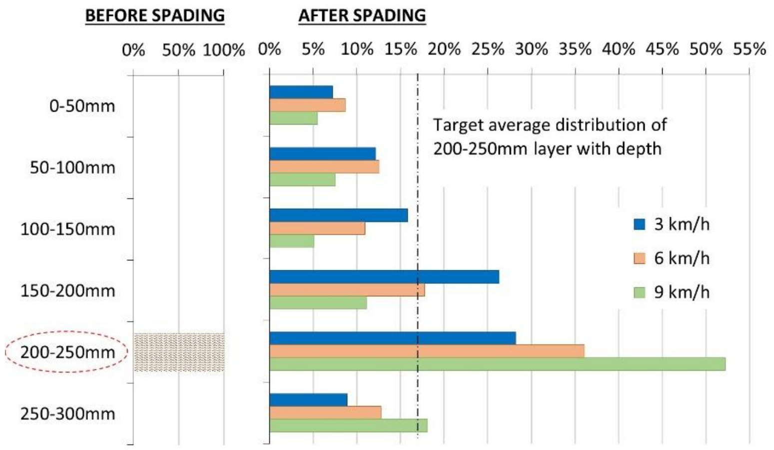

Figure 5: Simulated mixing outcomes of the 200-250mm deep layer within a 300mm deep spaded profile at 3 contrasting speeds (% indicate the re-distributed proportions of the original 100% of the 200-250mm layer)

The spading simulation at 300mm depth shows some ability to bring up some soil (13-20%, minimum at the high speed) from the 200-250mm 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 250-300mm deep 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 up into the topsoil.

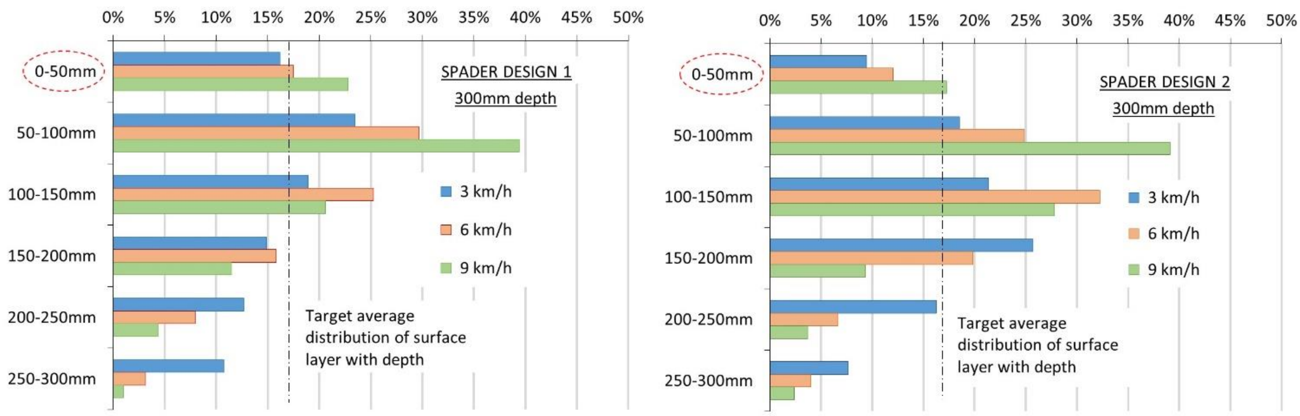

Figure 6: Simulated effects of spader design on the top-layer distribution with depth following spading to 300mm depth at 3 speeds (% scale indicates the re-distributed proportions of the original 100% surface 0-50mm layer) – Note: Design 1 uses sets of three large blades around the rotor and Design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

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 6 small left-and right-hand blades spread around the rotor) was slightly better able than design 1 (with sets of 3 full blades spread around the rotor) to incorporate top layer particles deeper into the profile at slower speeds, also displacing the bulge deeper into the profile (from 50-100mm at 9 km/h to 150-200mm at 3 km/h). These differences between brands disappeared 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

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

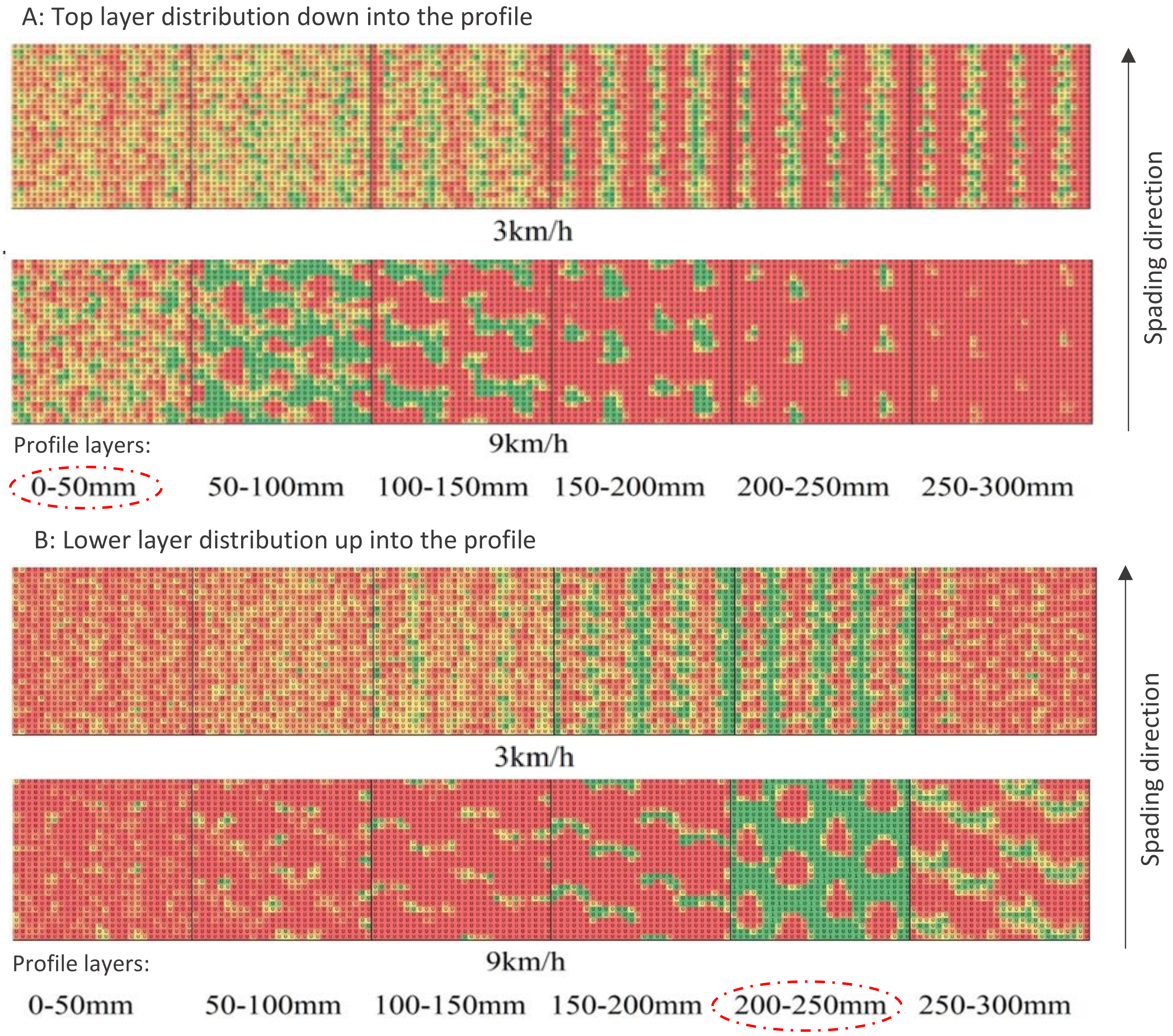

Figure 7: Top view simulation (50x50mm pixel resolution) of the distribution of 0-50mm top-layer particles (A) or 200-250mm deep layer particles (B), within individual layers of a 300mm deep spaded soil profile, at two speeds (Colour coding: light yellow to dark green indicates increasing concentration 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 ellipses mark the original layer of interest. *(source UniSA)*

Uniformity of mixing within layers

While Figures 3-6 showed 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. The figure contrasts the re-distribution within the spaded profile of the surface layer and of a 200-250mm deep layer at 3 and 9 km/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 3-dimensional pattern of mixing, in particular:

i) The visualisation of the 'bulge' of DEEP layer particles remaining in their original layer after spading (as was shown in Figure 5), showing portions of the 200-250mm 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.

ii) The visualisation of the 'bulge' of SURFACE layer particles in the layer immediately below (as was shown in Figure 3), and the localised release pattern in the layers below into distinct 'hot-spots', decreasing in size with depth.

iii) A similar banded contrast displayed at depth under low-speed spading, either from uncaptured sections of the original deeper layer or from 'hot-spot' features following entrainment of surface layer particles down the profile.

iv) The visual differences in surface soil particles left in that layer after spading as a function of context – e.g. the extent of unincorporated surface amendment, unburied surface weed seeds, or remaining surface water repellence.

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 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.

While crop responses to high uniformity spading is 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 soil/amendment mixing when ameliorating sandy soil profiles.

Power requirements

Research conducted in SA has shown that the spader PTO torque requirement is approximately proportional to forward speed or bite length. Conversely, the spader draught decreases with bite length, as the spader more effectively pushes itself along under greater forward speed. A zero net draught was found at 6 km/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 depth whereby the spader more actively pushes the tractor at any speed. The above features help explain how the overall tractor engine power requirement may be affected.

In-field measurements conducted in a sandy soil context in Upper South East SA (Ucgul et al., 2022), the engine power increased after a three-fold increase in speed (from 3 to 9 km/h) by 99% and 71% at 250mm and 350mm spading depth, respectively. This makes fast spading more economical per hectare, particularly when spading deeper, but as shown in the sections above, achieves a much lower mixing uniformity. In contrast, when spading 40% deeper from 250 to 350mm, a similar engine power increase of 95% to 68% was measured at 3 and 9 km/h, respectively, showing how the cost of deeper spading is much more significant, but in relative terms, also remains lowest at fast speeds.

In similar field trials, spading into a deep-ripped profile reduced the tractor engine requirements by 22% on average relative to unripped soil, with maximum power savings obtained under higher spading speed. Similarly, the power requirements of a second pass spading was 23% lower on average than an equivalent first-pass spading, across a range of depths and speeds, with best reductions occurring at high speeds. Commercial spaders are now available with optional pre-ripping tines (Photo 3).

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 ; Images courtesy of *Imants Spading Western Australia* (top) and *Farmax Spader - Groocock Soil Improvement* (bottom)

In both cases, the power reduction benefits of spading into a pre-loosened soil integrate the effects of reduced PTO torque, increased draught from reduced 'self-propelling', and slightly greater operating depth due to sinkage compared to spading into the undisturbed profile. Overall, these results highlight that the majority of power is expended from purely moving large volumes of soil during spading, whether from a pre-loosened or from an undisturbed base.

USEFUL RESOURCES

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GRDC Code:

CSP1606-008RMX (CSP00203)
USA1903-002RTX
