DISCS OR TINES?

Pros and cons and some new technologies

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Key findings:

Residue retention is the most important objective of no-tillage. Tined openers do not manage residues well. But many are capable of banding fertilizer better than disc openers and they are easier to adjust. Tines are therefore often seen as a less risky no-tillage option than discs. But as crop yields inevitably increase under no-tillage, discs become the only viable long-term option if conservation objectives are to be realised. Advanced disc/tined openers are capable of taking no-tillage in Australia to a new level by creating horizontal (instead of vertical) slots, micro-managing residues over the slots, and reducing slot disturbance to an absolute minimum. This combination of functions has already produced some of the highest crop yields and lowest failure rates ever recorded on properties where they have been applied.

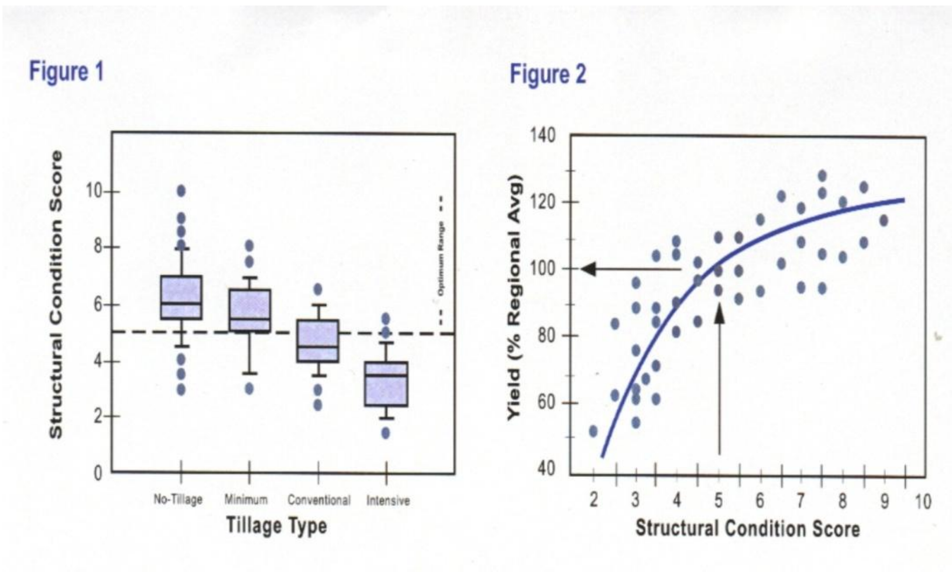
Abstract

No-tillage began world-wide, with residue-retention as its number one goal. By and large, this demanded disc openers. But unreliable stands, difficulty in banding fertilizer and mediocre yields forced farmers towards tined openers. In the process, new words, such as “soil throw”, entered the vernacular. But many of the original conservation objectives (of both soil and water) were lost in the move from discs to tines. This paper discusses the importance of surface residues, however scarce they might initially be in dry climates, and outlines the trade-offs between disc and tined openers in terms of residue management. *Micro-management* of surface residues (i.e., over and close to the sown slot) is a new concept for many no-tillage farmers but it will become increasingly critical to achieving true low-disturbance no-tillage and maximizing crop yields and soil health. The effectiveness of a range of no-tillage opener-types in performing 28 different functions is quantified by giving each function a numerical rating. Most disc and tined openers perform similarly but double discs are slightly “off-the-pace” and narrow tines were slightly superior. But the comparison also shows that there are other disc/tine options that clearly out-perform all others, and these claims are supported by independent USDA studies. Identifying and achieving the most critical of these performance criteria could plot a future direction for Australian no-tillage to follow.

The importance of residues

Like it or not, no-tillage is here to stay. And like or not, no-tillage is mostly about residues, even (or especially) in dry climates. It is not just a matter of ceasing general tillage. Nor is it about confining tillage to shallower surface layers (minimum tillage) or discrete rows (strip tillage). It is about simultaneously ceasing tillage altogether and carefully managing surface residues. When residues are ignored, no-tillage only achieves a small part of its objectives. Much of what no-tillage can achieve is driven by soil micro- and macro-organisms and these live on residues, each other, and soil carbon.

Simply ceasing tillage of the soil may slow down soil degradation. But it does little to rebuild soil structure or health. This is a biological process that is undertaken at no cost by soil microbes and other fauna. The most common physical measure of soil health is soil structure, which in turn is a strong determinant of crop yield. An extensive survey of arable farms in Canterbury, New Zealand illustrated the role of soil structure (Figures 1 and 2; Anon., 2001).



Structural score was highest under a no-tillage regime and crop yield improved as structural score increased.

Australia needs healthy soils to maximize crop yields and conserve precious soil water at least as much as other areas of the world. Indeed, the need may be even more acute in dry climates than in higher rainfall areas. The gains may be slower when moisture is already limiting but they will ultimately be more spectacular as the residues themselves create a new ecological balance in and on the soil that, to a large degree, is self-perpetuating. It is well known, for example, that 1 kg of humus holds as much water as 7 kg of clay and that bacterial decomposition is accelerated in the presence of moisture and that bacterial decomposition usually produces heat and humidity, which further accelerates the decomposition process and warms the soil in the process.

Cullinan and Derpsch (2006), following a study of Western Australian no-tillage, classified the importance of residues in Table 1:

Table 1: The effectiveness of surface residues for soil conservation

Less than 5%	Almost bare soil, lowest quality.
5 – 30%	Very low quality. Most residues are buried.
30 -60%	Low quality. Insufficient to control wind and water erosion.
60 -80%	Fair quality. Effective wind erosion control.
More than 80%	High Quality. Effective wind and water erosion control. High water infiltration. Effective reduction of moisture evaporation and weed control.

The aim should be to accumulate as much residue as possible over time. Even although a dry climate may not produce much residue to start with, it is a matter of best-utilizing that which it does produce and not wasting it. If the aim is to gradually improve soil health (and with it, crop yields) famers must learn to treat any residues they have as a precious resource rather than something that increasingly interferes with machine operation. While most people of the writer's generation were brought up to view cleanly ploughed fields as progressive, ICI Ltd was on the right track when it promoted no-tillage in the 1960s as "farming ugly". It is interesting to now observe that no-tillers regard residue-covered fields as progressive and ploughing as ugly – or worse, environmentally irresponsible.

And it is the issue of residues that largely fuels the disc-versus-tine opener debate, even although debaters often do not realise this. Many simply see the choices as being dictated by which machine is cheaper, which is easiest to use and which has the greatest risk of failure. Tine openers are cheaper and easier to operate than discs and they band fertilizer more easily. But they are poor managers of surface residues and are therefore usually arranged in wide rows at a time when narrower rows should be preferred because of the improved moisture reserves in untilled soils. "Soil throw" has become a buzz-word amongst no-tillers in parts of Australia. This suggests that some "soil throw" is seen as inevitable. But of course "soil throw" also means "residue throw" and this is more detrimental than "soil throw". The first aim of any no-tillage regime should be to reduce "soil and residue throw" to the absolute minimum. This is difficult to achieve with tine openers and even difficult to achieve with some disc openers.

While, by definition, disc openers might be expected to handle residues better than tines, they are more expensive and complicated and many are incapable of banding fertilizer at the time of seeding without doubling-up on the number of openers being used. This, in turn, negates much of the low "soil and residue throw" that might otherwise be considered advantages of individual disc openers. But not all disc openers are in the "low throw" category anyway. And many make a poor job of managing residues in other ways, such as hairpinning.

Another issue is that most no-tillage practices (regardless of opener type) increase crop yields to a greater or lesser extent. As a result, a choice of tined opener that might have been a relatively simple decision made on economic grounds may soon become more complicated if the higher-yielding crops create new residue levels that were never contemplated in the first place.

The 4th World Congress on Conservation Agriculture, in New Delhi, India, in February 2009, declared three essential requirements for effective Conservation Agriculture or no-tillage (Anon, 2009), each of which is influenced by residues:

- Minimum mechanical disturbance of the soil (*synonymous with minimum disturbance of the residues*)
- Permanent organic cover of the soil surface (*using either living cover crops or dead residues*)
- A diversified sequence of association of crops (*often desirable rotations are limited by the residue handling ability of machines*)

The aim of this paper is to compare the critical attributes of a range of no-tillage opener and drill types (disc, tine, and combination disc-and-tine) by placing values on each function in order to provide an objective basis for decision making.

What are the critical functions of no-tillage openers and drills?

The following opener and drill functions (in no particular order) have been shown to affect the success or failure of no-tillage crops and soil health (Baker, *et al,* 2006). Ultimately, they affect the profitability of arable cropping and/or the sustainability of no-tillage practices themselves.

1. Ability to mechanically handle heavy residues without blockage
2. Leave 70+% of the original residues in place after passage of the drill
3. Trap moisture vapour in the slot in dry soils using residues as slot cover
4. Avoid placing seeds in hairpins (either by not creating hairpins or by avoiding placing seeds in any that are formed)
5. Ability to maximize in-slot aeration in wet soils
6. Avoid in-slot soil compaction or smearing in damp soils, or at least avoid allowing any that are formed, to dry.
7. Maximize soil-seed contact, even in greasy ("plastic") conditions.
8. Self-close the slots.
9. Mitigate slot shrinkage when soils dry after drilling.
10. Ability of individual openers to faithfully follow ground surface variations as large as 300 mm.
11. A greater-than-normal range of vertical travel of individual openers
12. Ability to maintain consistent downforce on openers throughout range
13. Ability of openers to seed accurately at shallow depths (12-15 mm)
14. Ability of opener downforce to auto-adjust to changing soil hardness
15. Simultaneously band fertilizer with (but separated from) the seed.
16. Ensure that fertilizer banding is effective with high analysis fertilizers.
17. Ability to handle sticky soils.
18. Ability to handle stones.
19. Avoid bringing stones to the surface.
20. Functions are unaffected by hillsides.
21. Minimal adjustments required when moving between conditions.
22. Ability to maintain most critical functions at high speeds.
23. Wear components are self-adjusting.
24. Design life of whole machine matches the tractors that pull it.
25. Low wear rate of soil-engaging components.
26. Wear components (including bearings) are cheap and easily replaced.
27. Requires minimal draft from tractor.
28. Proven positive impact on crop yield.

Table 2 attaches a rating value (where 1= poor and 5 = excellent) to the 28 factors listed above for 7 generic opener types, according to known existing scientific and field-performance data. Adding all of the rating values together in Table 2 creates an overall rating for each opener or drill type, which is expressed as a percentage of the maximum possible rating of 140 (28 X 5). Of course, in some conditions, some of the functions listed in Table 2 may not apply. The reader is therefore invited to delete those attributes that do not apply and re-calculate the overall ratings for opener types. Attributes marked with an * may be deleted in certain circumstances. But all others apply universally.

TABLE 2: Comparisons of no-tillage opener types by function (Rating basis: 1 = poor; 5 = excellent)	Narrow Hoe	Wide hoe	Sweep	Double disc	Single disc	Slanted disc	Combo winged tine & disc
1 Ability to mechanically handle heavy residues without blockage	2	1	1	4	4	4	5
2 Leave 70+% of the original residues in place after passage of the rill	3	2	2	5	4	4	5
3 Trap moisture vapour in the slot in dry soils using residues as slot cover	3	2	3	1	2	4	5
4 Avoid placing seeds in hairpins	5	5	5	1	2	2	5
5 Ability to maximize in-slot aeration in wet soils*	3	4	3	1	3	3	5
6 Avoid in-slot soil compaction or smearing in damp soils*	1	1	3	1	5	5	5
7 Maximize soil-seed contact, even in greasy ("plastic") conditions	4	3	4	3	3	4	5
8 Self-close the slots	2	1	3	2	3	4	5
9 Mitigate slot shrinkage when soils dry after drilling*	3	5	5	1	2	4	5
10 Ability of individual openers to faithfully follow ground surface variations	2	1	2	2	4	2	5
11 A greater-than-normal range of vertical opener travel of individual openers	2	1	1	2	2	1	5
12 Ability to maintain consistent downforce on openers throughout this range	3	1	1	2	3	3	5
13 Ability of openers to seed accurately a shallow depths*	2	1	1	2	2	1	5
14 Ability of opener downforce to auto-adjust to changing soil hardness	1	1	1	1	1	1	5
15 Simultaneously band fertilizer with (but separate from) the seed	5	5	5	1	2	3	5
16 Ensure fertilizer banding is effective with high analysis fertilizers	5	5	5	1	1	2	5
17 Ability to handle sticky soils*	5	5	4	1	3	3	2
18 Ability to handle stony soils*	4	3	1	4	4	2	4
19 Avoid bringing stones to the surface*	1	1	1	5	5	3	5
20 Functions are unaffected by hillsides*	5	5	4	5	2	1	5
21 Minimal adjustments required when moving between conditions	3	3	3	4	1	1	5
22 Ability to maintain most critical functions at high speeds	3	1	1	4	3	3	5
23 Wear components are self-adjusting	5	5	5	3	2	2	5
24 Design life of whole machine matches the tractors that pull it	4	4	4	2	2	2	5
25 Low wear rate of soil-engaging components	5	4	4	2	3	3	3
26 Wear components (including bearings) are cheap and easily replaced	5	5	4	2	2	2	4
27 Requires minimal draft from tractor	4	3	2	5	4	3	3
28 Proven positive impact on crop yield	3	2	2	1	3	4	5
TOTAL SCORE	93	80	80	68	77	76	131
RATING SCORE AS A PERCENTAGE OF POSSIBLE (140)	**66**	**57**	**57**	**49**	**55**	**54**	**94**

CONCLUSIONS FROM TABLE 2

Not surprisingly, neither pure disc nor pure tine openers rated particularly highly. The highest rating of these opener-types was the “narrow hoe” at 66% of the possible score of 140. The best of the pure disc openers was “single disc” (55%) and “slanted disc” (54%). All three pure disc openers rated slightly less than all three tine openers, but the differences were not large. To all intents and purposes it would be fair to say that there was little to choose between any of the pure disc or pure tine openers, with the possible exception of the narrow hoe, which appears to be slightly superior to all other opener types except the “combo winged tine and disc” opener (otherwise known as Cross Slot™).

The latter opener is in a class of its own. It combines the best attributes of pure disc openers with the best attributes of pure tine openers and adds a few new and unique functions of its own. In so doing, it attained a rating of 94%, which was clearly superior to any of the other openers. In fact, the rating of this opener was superior to the “best scores” of all of the other openers combined. This is hardly surprising, since the design arose from 30 years of published biological research that began in 1967 with the aim of identifying the reasons for biological failures by other openers. The superiority of the “combo winged tine and disc” (Cross Slot) opener has been independently verified (in 2007 and 2008) by the USDA’s “Revised Universal Soil Loss Equation 2” (RUSLE2) ranking system. Tables 3 and 4 show the results.

TABLE 3: Wasco County, Oregon, USA establishing 3.3 tonne/hectare (50 bu/ac) winter wheat crops in the following rotations (winter wheat - either chemical or conventional fallow – winter wheat)

TILLAGE OR SEEDING SYSTEM	Predicted soil loss t/ha/yr	Soil Condition Index SCI	Soil Tillage Intensity Rating STIR	Estimated fuel use for entire 2-year program l/ha
Mouldboard ploughing	21.11	-0.46	91.2	70.21
Anderson min- tillage opener	0.79	0.66	10.6	23.40
Single disc no-tillage opener	0.22	0.73	3.07	21.53
Cross Slot no-tillage opener	0.058	0.77	1.20	20.59

Source: Eddy, D. (2008) NRSC, USDA, The Dalles, OR (personal communication 2008)

TABLE 4: North Dakota State University, Dickinson, North Dakota, USA, establishing spring wheat after sunflower without prior tillage

NO-TILLAGE OPENER CONFIGURATION (including row spacing in cm)	Soil surface disturbance %	Soil Tillage Intensity Rating STIR	Estimated fuel use for one spring seeding event (spring wheat into sunflower residues) l/ha
Double disc (18-25)	65	6.33	3.37
Double disc with separate fertilizer opener (18-30)	85	13.81	4.02
Double disc with fluted leading disc (18-25)	55	7.15	4.02
Double disc, narrow offset	25	4.87	3.00
Double disc, very heavy one-pass direct seeding	85	16.57	10.30
Double disc, very heavy one-pass direct seeding with row cleaners	90	17.55	12.17
Hoe in heavy residue (25-38)	65	16.90	6.93
Hoe (15-30)	90	23.40	6.93
Single disc (18-25)	15	2.43	3.28
Single disc with separate fertilizer opener (18-25)	35	5.68	4.49
Cross Slot (18-25)	15	1.95	3.74

Source: Nowatzki et al (2007)

Conclusions from the Oregon estimates (Table 3):

(a) Cross Slot no-tillage seeding was superior to each of the other tillage or seeding systems in each of the four indices reported.
(b) The biggest difference between treatments suggests that the predicted soil loss using Cross Slot no-tillage would be 364 times less than mouldboard ploughing.

Conclusions from the North Dakota estimates (Table 4):

(a) Despite minimal residues from the preceding sunflower crop, Cross Slot no-tillage produced a superior (lower) STIR rating to each of the 10 other no-tillage and minimum-tillage openers.
(b) No competing openers produced less soil surface disturbance than Cross Slot openers. Single disc openers were equal with Cross Slot in this respect and both produced 1/6 the amount of soil disturbance as the "very heavy double disc opener with row cleaners".
(c) Only 3 of the 10 other openers (double disc, single disc and narrow offset double disc) appeared to use less fuel than Cross Slot no-tillage openers. But these three openers did not sow fertilizer, which was applied separately and therefore consumed additional fuel that was not recorded in these tests.

Combined conclusions from tables 3 and 4

The following conclusions may be drawn from both sets of USDA data:

- On the basis of the key RUSLE2 estimates at both localities, Cross Slot no-tillage was the highest ranking system in terms of its effects on soil health, quality and sustainability and also had a lower carbon footprint than most.
- It is likely that improved crop yields would result, as they usually do from improved soil health.
- The biggest savings in fuel-use were 71% by Cross Slot compared with tillage in the Oregon comparison and 75% by the Narrow Double Disc Offset opener compared with Very Heavy Double Disc opener plus Row Cleaners in the North Dakota comparison. Cross Slot used 69% less fuel than the latter opener system.

The difference between *macro-* and *micro- management* of residues

Macro-management of residues refers to the roles that residues play in relation to soil health across an entire field and the profitability of no-tillage as a practice. Most of the advantages of *macro-management* of residues are well known and proven. In most cases they are not so much a drill function as a harvesting function. They include;

- Reducing soil erosion (wind and water) by slowing the velocity of both wind and water at the soil surface.
- Reducing pollution of streams, lakes and waterways by reducing run-off that otherwise contains pollutants.
- Retaining soil moisture and lowering soil temperatures through shading.
- Reducing weed seed germination by shading.
- Rebuilding soil structure by feeding soil fauna and microbes, which in turn, bind soil together with exudates.
- Increasing infiltration, indirectly by improving soil structure, and directly by increasing bio-channels.
- Supplying nutrients as the bi-products of decomposition.

Micro-management of residues is not just *macro-management* on a small scale, although all of the advantages still apply. *Micro-management* refers instead to how the residues are specifically managed close to or over each sown row. In the main, *micro-management* of residues is a drill function. The following not-so-well-known facts can have an important impact on the success or failure of any no-tillage event.

- Residues swept aside by no-tillage openers, divert earthworm activity away from the sown rows. Earthworms are important aerators of soil in wet conditions and nutrient recyclers in any soil. They respond directly (even within a few centimetres) to where the residues are positioned.
- In-row infiltration and aeration respond strongly to earthworm activity (or lack of it) within (as opposed to between) the rows.
- Residues placed over sown rows trap water vapour in the seed zone, which in turn has a major impact on seed germination and seedling emergence in dry soils. Loose soil is better than no cover at all, but residue-over-loose-soil is a significant further improvement.
- Residues placed over the sown rows reduce in-row scouring by erosion when high rainfall events follow drilling that has taken place up and down slopes (as is sometimes unavoidable).
- When seeds are placed in “hairpinned” residues (uncut straw pushed – doubled up - into the sown slot) they may be killed by acetic acid produced by anaerobic fermentation of the residues in cold damp soils.
- But separation distances between seeds and residues of as little as 10 mm will prevent acetic acid mortality because soil bacteria break down acetic acid close to its source of fermentation.
- Residues mixed with sticky soils significantly reduce the soil’s stickiness, making machine operation simpler.
- There is not a disc in existence that can cut all of the residues all of the time. No-tillage openers must therefore always be able to cope with a proportion of uncut residues.
- Chopped residues are easier to cope with than un-chopped straw when using openers that do not handle residues well, but are no particular advantage with openers that do handle residues well.
- Long standing stubble can assist openers that have limited residue-handling ability and will also provide wind protection to emerging seedlings.
- On the other hand, long stubble takes longer to decompose and provides less protection against raindrop impact than when it is cut lower and left as straw lying on the ground surface.
- The fine chaff (tailings) from combine harvesters sometimes creates a denser mat of residue than straw alone, and this may affect some openers and not others.
- Few, if any, residues of agricultural plants are allelopathic (or toxic to other plants) as was first assumed to be the case when the causes of regular no-tillage drilling failures could not be otherwise explained.
- Residues can however, harbour certain pests and diseases that are best dealt with either pesticide applications at the time of drilling or crop rotations, preferably the latter.

Conclusion

Most people, who have experienced the benefits of no-tillage in any form, will appreciate that the next step will be to refine the system in order to make it as effective and profitable as possible. Current “no-tillage” practices are a long way from being as good as they could be, even although they are on the right track.

This paper examined some of the most critical factors that will respond to refinement. The majority of these relate in one way or another to *micro-management* of crop residues.

The ultimate goal is to improve both sustainability and profitability. These two factors need not be competitive. Indeed the machines and techniques required to maximize sustainability are the same ones that will maximize profitability.

Profitability is comprised of two things:

(a) Maximizing crop returns
(b) Minimizing costs

Sustainability is being able to repeat these two factors without threatening soil health.

Low disturbance no-tillage contributes to both profitability and sustainability, when undertaken correctly.

Low disturbance no-tillage is now producing some of the highest crop yields ever recorded anywhere. This reflects the fact that we now know that untilled soils have always had more potential to maximize crop yields than tilled soils ever had. But we are only now learning how to harness that potential. Any soil disturbance or inversion (however small and localized) obstructs the harnessing process by interrupting the development of millions of “new” biological colonies and eco-systems that are at the heart of this “new” soil resource. For centuries, tillage has been shifting the biological balance of soil to one side for no greater gain than mechanically controlling weeds. In the process, we have been destroying myriads of beneficial micro-organisms, including those that are natural predators of the very diseases and pests that have forced us to develop other (often environmentally unfriendly) pest- and disease-control measures.

Low-disturbance no-tillage changes all of that.

True low-disturbance no-tillage is a genuine single-pass activity. While this might demand sophisticated machines, a single pass with such a machine will, almost invariably, be cheaper than two passes with less-sophisticated machines. Nor has anyone yet been able to duplicate the level of crop performance that a highly-sophisticated low-disturbance no-tillage machine can produce, by substituting either cheaper or higher-disturbance equipment.

Forward-thinking farmers no longer question whether or not no tillage works. Nor do they question whether or not no-tillage is good for the environment. The only remaining question they ask is which is the best way to achieve it? This involves learning how to *micro-manage* crop residues and to treat these same residues as one of the most precious resources available on their farms.

This is where Australian no-tillage should be heading.

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