# Reducing risks at seeding

# Dr C John Baker

## Introduction

The vast majority of the world's food supply starts as sown agricultural seeds. Only fish (which contributes 1% of the world's food supply – Boulag, 1994) does not trace any part of its growth to terrestrial seeds. Therefore, few things that man does in agriculture are more fundamental to food supply than sowing seeds. Failure at this point translates to failure through the whole food chain.

## History of risk in no-tillage

When man first learnt to plough, he thought he had pushed nature firmly in his favour by burying weeds that otherwise competed with his ever- improving domestic plant species. Little did man know that ploughing was also silently destroying other aspects of the very soil environment that these same seeds were being asked to grow in. As he became aware of the role of carbon in the soil and how repeat-ploughing was depleting it, man began to accept the need to find other ways of preparing seedbeds than ploughing or tillage.

The modern era of "no-tillage" was conceived in the 1960s. Although New Zealand had earlier demonstrated that pastures could be established by drilling without tilling the soil (Robinson and Cross, 1957) it was only when non-residual herbicides were developed in the 1960s that the practice became viable for arable cropping. Australia was one of the first countries to see potential in the new concept, based mainly on its ability to conserve soil water.  This author's focus on reducing the risks at seeding started with observations he made in dry Hawkes Bay, New Zealand and the then ICI Research Station at Wagga Wagga, NSW in 1967.

Within a short period of the new techniques of no-tillage being shown to be feasible (even if it was still far from risk-free) conservationalists and soil scientists began finding huge environmental benefits when ploughing stopped and residues were returned to the soil to slowly decompose and sequester carbon back into the soil. In some ways though, the rush to embrace the new practice of no-tillage (or "direct drilling" as it was first known) also had a negative effect that still lingers today.

The advantages of no-tillage were seen as so important and urgent that farmers were urged to accept the possibility of reduced yields and/or periodic seeding failures for the good of mankind. A small number did so. But the novelty soon wore thin. No farmer wanted to reduce his/her yields, no matter how much cost was taken out of the system. Feeding their families today became more of a priority than saving the world's soils for tomorrow.

Although chemically-assisted no-tillage originated in the UK (driven by the advent of paraquat) it was the USA that provided the greatest long-term impetus, driven largely by the advent of glyphosate and the need to reduce soil erosion. Australia and Canada focused more on conservation of soil water but erosion-control was also a driving force. Regardless of which driving force prevailed, residue-retention became the single most important goal, and this favoured disc openers. But stand failures with disc openers were frequent and yields were mediocre because of the difficulty of banding fertilizer at seeding. So a gradual swing towards tined openers occurred. Banding fertilizer was easier with tines. Hairpinning was rare. And stands were more reliable. But tined openers do not manage residues well and they create considerable unnecessary soil disturbance. They sweep residues aside. So, wider and wider rows became accepted and much of the conservation objectives of residue-retention were lost.

The conundrum between disc and tined openers has left us where we are today. Either way, there is risk. But understanding these risks will provide several pathways forward.

## What are the risks at seeding?

There are visible and invisible risks:

> **Visible risks** result in impaired seedling emergence at seeding.
>
> **Invisible risks** show up later as impaired crop yields.

The important thing is that the design of no-tillage openers can have significant effects on either or both.

When the soil is tilled, it is the tillage implements and processes that have the greatest effects on both visible and invisible risks. Seed drills have only a small influence.

But when no-tillage is used, the seed drill is the sole machine that influences risk at seeding.

## Visible risks

No-tillage openers and drills influence several factors that in turn influence seedling emergence:

- **Germination.** Opener design influences how and in what form water is obtained from soil by seeds. In this respect, untilled soils have an important additional resource compared with tilled soils, which is vapour-phase water or humidity. The main usable source of water in a tilled soil is liquid water in the form of colloidal films surrounding soil particles. All farmers have become used to recognising and judging when a soil contains enough liquid water to germinate seeds. But vapour-phase water is another matter because it is largely invisible and soil colour does not change with the amount that is present. Nonetheless, all untilled soils contain 100% relative humidity (RH) in their pore spaces at all moisture contents within the plant-available range (i.e. from “field capacity” at the wetter end down to “permanent wilting point” at the dry end). For the purists, pore-space RH actually declines to 99.8% at “permanent wilting point” (Scotter, 1976).

When soils are tilled, much of this pore-space RH escapes into the atmosphere and plays only a minor role in germination. But when soil remains untilled, all of the RH is available. Most seeds can germinate in an atmosphere of 90-100% RH without any soil-seed contact at all, which otherwise has the function of maximizing liquid-phase water uptake. But most no-tillage machine designers still believe that the most important requirement for seeds is good soil-seed contact, even under no-tillage. So they design their machines to disturb the soil in the sown slot. In so doing they unwittingly ensure that this disturbed zone becomes the only part of the untilled soil that loses its RH to the atmosphere. Even although the undisturbed soil between the rows might retain 100% RH, seeds end up in a disturbed zone that provides no better resource for germination than a tilled seedbed, which has always been problematic in a dry soil.

Before the crop even begins to grow, such machines already put the seeds at unnecessary risk by wasting one of the unique resources that untilled soils offer.

Tined openers are the worst culprits. Wide sweeps are especially guilty.

The aim should be to create seed slots without inverting or excessively disturbing the soil but instead ensuring that they trap maximum water vapour. If they also have liquid water available, that is a bonus. This objective is best achieved by creating horizontal slots (rather than the more common vertical slots) and covering them with whatever surface residues are present. This is known as *micro-management* of surface residues. Residues are nature's barrier to soil moisture loss and are far more effective than loose soil, which nonetheless is better than no cover at all. A super-dry dust mulch can sometimes substitute for surface residues, but the same principles apply – i.e. it should remain the covering medium after the drill has passed rather than be swept aside during seeding. While surface residues might be scarce in dry climates, over time no-tillage will increase yields and with them, the volume of surface residues available. So the process becomes self perpetuating, which suits most (but not all) disc openers.

The best solution is disc openers that create relatively-narrow low-disturbance horizontal slots covered with residues. It does not include wide sweeps because they disturb the soil and residues too much to be regarded as true no-tillage tools. 50% wheat seedling emergence has been obtained from low-disturbance horizontal slots at -12 bar soil moisture stress in an experiment designed to test the limits of humidity-assisted germination in an extremely dry soil (Baker *et al*, 2006). This soil was close to "permanent wilting point" (-15 bar) and would normally be considered much too dry in which to sow seeds. It is doubtful if any seedling emergence at all would have occurred if this same soil had been tilled. Certainly, no seedling emergence occurred from the two other types of vertical no-tillage slot that were also compared in the same experiment. In fact, those wheat seedlings that did emerge subsequently died of moisture stress. What the experiment illustrated therefore, was that the soil has more potential to germinate seeds than to sustain their growth, provided that we learn how to harness that potential.

Nor does pore space humidity appear to be sensitive to soil temperature. This author measured similar humidity differences between the slot micro-environments of vertical and low-disturbance horizontal no-tillage slots in a soil at 45°C at Katherine, Northern Territory, Australia (C. J. Baker, unpublished data, 1980).

- **Seedling emergence.** In a tilled seedbed, good germination almost guarantees good seedling emergence. But this is not necessarily so under no-tillage!

  When drill openers penetrate untilled soils they create interfaces (slot walls) between the disturbed slot- zones and the undisturbed soil alongside. In tilled soils, no such interfaces are formed because all of the soil has been pre-disturbed (tilled) before the drill passes. In tilled soils, drill openers simply re-disturb an already-disturbed soil without forming any distinguishable slot walls.

  But when embryonic roots encounter these slot walls in a no-tilled soil, they may "bounce" off them. The more vertical the walls the more likely they are to "bounce". And if the walls are smeared or compacted the problem is even greater. Further, because vertical no-tillage slots are often difficult to close, smeared walls often dry internally to form hard crusts that are even more difficult for roots to penetrate.

  The result can turn adequate counts of germination into poor counts of seedling emergence because of a high rate of sub-surface seedling mortality. Dead seedlings under the soil are not visible from the surface. Sub-surface seedling mortality is therefore often wrongly assumed to be poor germination. Double disc (and to a lesser degree, single disc) openers are the worst culprits, but tined openers are not immune either, especially when they smear the walls of a slot in a damp and "plastic" soil at the time of drilling.

  Low-disturbance horizontal slots avoid this problem because (a) they do not have vertical slot walls, (b) their micro-environments are always humid, and (c) their seed zones are never allowed to dry and form internal crusts.

  In support of the claim that seeds and seedlings are "cocooned" in humid low-disturbance horizontal slots, germinated-but-un-emerged ryegrass seedlings have been found alive under the soil in New Zealand some 8 weeks after drilling into a residue-covered volcanic soil with low water-holding capacity that received no rainfall at all for 8 weeks post-drilling. Rain in the 9$^{th}$ week brought the seedlings to the surface apparently none-the-worse for their 8-week period of "suspended hibernation" beneath the soil.

- **Seeding depth control.** Seedling emergence and maturation of growing crops benefit from consistent seeding depths, which are relatively easy to achieve under tillage because the soil is artificially homogenised and smoothed by the tillage implements. But under no-tillage, there is a real risk of inconsistent seeding depths arising from variable soil surfaces and densities.

  Amazingly, many drill designers still seem to pay lip service to this critical function by designing machines that push openers into the ground with springs that vary their downforces linearly with length and have no way of automatically responding to changes in soil density. Fortunately there are other designs that specifically target consistency of downforce over an extended range of opener-travel (up to 450 mm) so as to negotiate uneven surface terrain. Further, in the most advanced designs this downforce can be varied automatically on-the-move several times per second in response to changes in soil density that occur naturally across every no-tilled field. Realistically, this involves individual hydraulic cylinders on each opener as the primary cushioned downforce sources, adjustable gauge wheels and electronic sensing devices strategically located on monitoring openers.

- **Slot shrinkage.** Even the best made no-tillage slots of any shape will shrink open if they are created in a damp shrinking soil that dries after seeding. With vertical slots, this is one of the most common causes of failed establishment because the seeds become exposed to both climatic and pest damage. It is a risk that cannot be predicted or controlled and is more a function of soil type and climate than opener design. But low-disturbance horizontal slots have a clear advantage in mitigating its effects. By creating horizontal shelves either side of a central vertical disc slit and folding soil and residues back over these shelves as covering flaps, when slot shrinkage occurs, only the central slit shrinks and the seeds remain tucked off to one side of the slot in a high-humidity zone created by the horizontal shelves and their covering flaps.

- **Seed vigour.** All certified seeds are tested for *purity* and *germination* under international seed-testing protocols (“P and G” tests). But vigour-testing is not standard practice for most seed testing organisations even although most have the ability to undertake them as a matter of course for high-value seeds such as vegetables. Vigour-testing (or “accelerated aging tests”) involve a special test intended to show how seeds perform under stress (seed vigour). A hint of the presence of a low-vigour seed line may often come from low interim-counts during normal P and G tests. In any case, the importance of low-vigour seed lines in no-tillage should not be under-estimated.

  When low-vigour seeds that have otherwise passed P and G testing, are sown into tilled soils they will often delay germination and emergence until soil conditions become very favourable. And even then the resulting crop may be weak. These late germinating and poorly performing crops are often accepted as due to a multitude of unidentified factors. Few people ever test such seed lines for vigour. But in well-made (low-disturbance horizontal) no-tillage slots, the micro-environment is so favourable that even low-vigour seeds will often germinate even although few of the seedlings will emerge. Excavation of the slots may find twisted seedlings. This is often wrongly attributed to “fertilizer burn” when in fact it is more likely to indicate that a low-vigour seed line had been sown in the first place. Fertilizer “burn” does not twist seedlings. It “burns” them. Only hormone herbicides or poor vigour causes sub-surface seedling twisting.

  Sowing untested seed can therefore increase the risk of failure.

- **Fertilizer “burn”.** There is now little debate about the advisability of banding fertilizer with the seed at the time of drilling under no-tillage. Some no-tillage openers facilitate this. Others do not. When soils are tilled, nitrogen and other nutrients are mineralized by the tillage process making them readily available to the sown seeds in a safe form. Never mind that they are derived (“mined”) from the soil organic matter, which helps deplete this precious resource when repeat tillage takes place.

  But under low-disturbance no-tillage, less mineralization takes place. Further, as surface residues decay, nitrogen is often temporarily “locked up” by the decomposition process, making it unavailable to the new seedlings as the C:N ration swings towards the carbon side. Although the “locked up” nutrients will be released later in the growth cycle as the micro-organisms die, the early effect is often yellowing of seedlings and weak early plant growth of no-tillage crops in the absence of applied fertilizer. But surface-broadcast nitrogen is often ineffective in countering the problem because much of it runs preferentially down the bio-channels that remain in undisturbed soils and bi-passes the juvenile root systems.

  The need for simultaneous banding of fertilizer is therefore much higher under no-tillage than tillage. But care needs to be taken that banding does not create chemical “burn” of the seeds. Certainly mixing the two together will likely burn the seeds even although this is a practice that is sometimes promoted as a viable solution with drills that have no ability to separately band fertilizers with high salt concentrations. Damage is possible from most forms of nitrogen and potassium, together with elemental sulphur and boron. Some forms of phosphorous are reasonably safe to be mixed with the seed at light dose rates (e.g. MAP and DAP) but others such as super-phosphate can be injurious, especially when there is free sulphuric acid present.

  There appear to be only minor differences between horizontal or vertical separation of fertilizer bands, possibly favouring the horizontal option. But the “2 plus 2” rule (2 inches across and 2 inches down) applies only to tilled soils. It appears that separation distances greater than 1 inch (25 mm) in any direction during no-tillage reduces the effectiveness of the fertilizer being banded. Therefore the need for banding-accuracy under no-tillage is acute if maximum response is required but “fertilizer burn” is to be avoided.

- **“Hairpinning”.** Hairpinning (or tucking) of surface residues into slots during seeding occurs when a proportion of the residues are not cut by discs but are instead pushed doubled-up and uncut into the slots and seed is deposited in the hairpinned straw. In dry disturbed slots this interrupts soil-seed contact and therefore reduces liquid water uptake. In wet anaerobic soils, fatty acid decomposition of the hairpins may kill seeds that are touching the straw and sometimes also seedlings.

  Most disc openers are particularly vulnerable to hairpinning problems. Tined openers seldom encounter the problem. But then again tined openers do not handle heavy residues well in the first place. Again, low-disturbance horizontal slots avoid the problem by depositing the seeds to one side of any hairpins that are formed by the central vertical disc. Soil bacteria quickly break down the destructive fatty acids. Separation distances as little as 10 mm are therefore usually effective.

- **Pressing.** Pressing on the soil that covers no-tillage slots appears to have little or no beneficial effect. Pressing on seeds at the base of a vertical slot prior to covering is much more effective because it ensures that juvenile roots emerge directly into undisturbed soil and therefore do not have to negotiate any slot walls.

- **Allelopathy.** In the early days of no-tillage, unexplained seedling emergence failures were often attributed to allelopathy, which is the ability of certain plants to poison the ground around them to protect themselves from competition. This explanation also seemed to satisfy those who had prophesised doom and gloom for the no-tillage industry when it first started.

  But once the real seedling emergence risk-factors had been identified and corrected, this author has never seen a genuine case of impaired seedling emergence or plant performance that turned out to be caused by allelopathy. It has turned out to be a non-issue.

## Invisible interactions

Invisible risks are those that do not show up as impaired germination or emergence, but rather manifest themselves at a later stage as reduced crop yields.

- **Fertilizer banding.** The effects of early nutrient shortages are both visible and invisible. Early yellowing of seedlings is a visible effect and can be mitigated by judicious banding of fertilizer at the time of seeding. But final yield reductions may also be limited by the methods of fertilizer application at seeding.

  With most spring-sown no-tillage crops except maize, most of the crop's total nutrient requirements are best applied by the drill openers at seeding, so long as the openers have that capability and "fertilizer burn" is not a risk. But with autumn-sown crops and maize, only starter quantities are often applied at seeding because post-emergence application(s) will be planned to occur with separate application methods. Sometimes the same openers that sowed the crop can double as sub-surface fertilizer-only injectors during crop growth. All of the same ground-penetration and residues-handling issues will exist during this side-dressing function but a precise depth control function is not as critical.

  In any case, if the rates of fertilizer required are found to be greater for no-tillage than for tillage, this is usually a clear indication that the no-tillage system or machines being used are not doing their jobs properly. If anything, good no-tillage will reduce the amount of added nutrients required, not increase them.

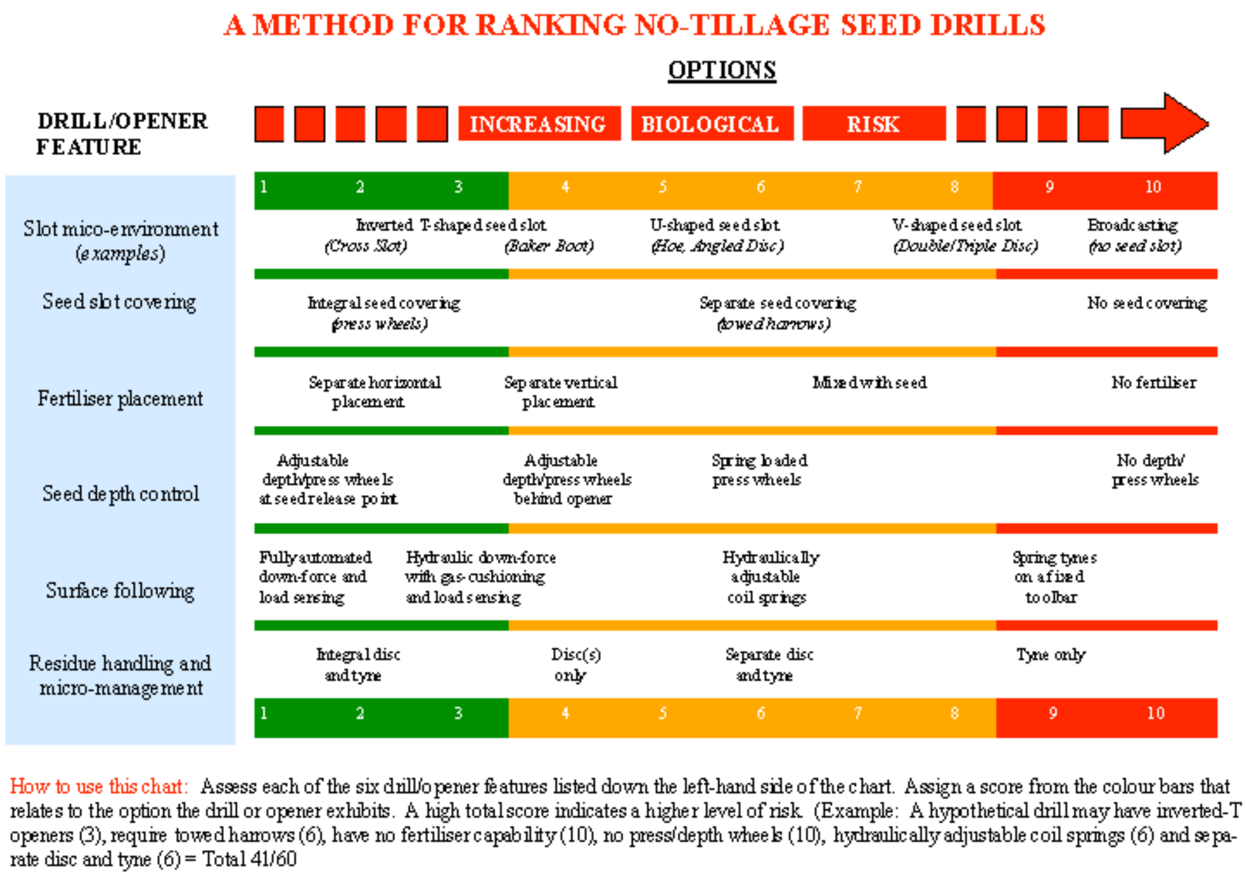
- **Seedling vigour.** There is a body of physiological opinion that holds that the yield potential of most agricultural plants is, in part, determined before the seedlings even emerge from the soil, as a function of the energy they expend during the germination and emergence process. Even when a similar number of seedlings emerge from two slots created by two different no-tillage openers, the theory holds that those seedlings that were least stressed during the emergence process will have a greater yield potential than those that underwent invisible sub-surface stresses before emergence.

If this theory is correct, it might help explain the superior crop yields obtained from slots with known humidity-retention properties compared with those that rely on liquid-phase water alone to germinate the seeds (and also compared with those in fully-tilled soils).

- **Soil microbiological activity.** It is now widely accepted that conventional tillage has been destroying millions of soil microbes, which are only now showing us what their true contributions might have been to soil fertility, sustainability and plant growth if we had left them alone in the first place. This suggests that any soil disturbance, even within the slot, takes us at least part-way back towards the skewed microbial balances of soils that have been subjected to general tillage. While minimizing soil disturbance by drill openers would seem an obvious goal, this must be achieved in a manner that also preserves the other desirable micro-environmental functions of openers and avoids the detrimental side effects that have been outlined.

To maximize the beneficial interactions at seeding, no-tillage openers should therefore be designed from a biological viewpoint rather than a mechanical viewpoint. Sadly few have been. And assumptions that the things that are desirable about tilled soils must also be desirable in untilled soils (with adjustments mainly for soil hardness) are sadly misguided.

*Table 1.* A biological risk-assessment chart of drill opener designs (after Ritchie *et. al*. 2001).




## References


**Anonymous (2009).** The New Delhi Declaration on Conservation Agriculture. *Proceedings of the 4th World Congress on Conservation Agriculture, New Delhi, India, 4-7 February 2009. (in press). (The Declaration is also available on request from the Food and Agriculture Organization of the United Nations, Rome Italy).*

**Baker, C. J.; Saxton, K. E.; Ritchie, W. R.; Chamen, W. C. T.; Reicosky, D. C.; Ribeiro F.; Justice, S. E. and Hobbs, P.R. (2006).** No-tillage Seeding in Conservation Agriculture. *CABI publishers, 350 pages. ISBN # 1 84593 116 5. (English and Russian translations)*

**Ritchie, W.R., Baker, C.J. and Hamilton-Manns, M. (2000).** Successful No-tillage in Crop and Pasture Establishment. (*Caxton Press, New Zealand, 96 pages*)

**Scotter, D.R. (1976).** Liquid and vapour phase transport in soil. *Australian Journal of Soil Research* 14, 33-41.