5 The Role of Slot Cover

C. John Baker

———————————

In no-tillage, nothing influences the reliability of seedling emergence more than the nature of the slot cover.

If you stand on the ground and look down on a seeded soil slot ('furrow' or 'groove'), after passage of a no-tillage drill or planter, you will see varying types of seed and slot coverage, which we have described in five 'classes' (Baker *et al.*, 1996):

1. Class I: visible seed (Fig. 5.1). Little or no loose soil covering the seed.
2. Class II: loose soil (Fig. 5.2). Loose soil and perhaps a small amount (less than 30%) of surface residue or mulch that has been induced back into the slot to cover the seed.
3. Class IIIa: intermittent mulch and soil (Fig. 5.3). There is a variable amount (30% or more) of residue or mulch on top of the loose soil covering the seed.
    Class IIIb: a mixture of residue and soil (Fig. 4.17). Thirty per cent or more of residues or mulch is mixed in with, rather than on top of, the loose soil covering the slot.
4. Class IV: complete mulch and soil (Figs 5.4 and 5.5). Soil and a covering of at least 70% of residue or mulch has been induced back over the slot in roughly the same layering positions as they were prior to drilling, i.e. with the mulch covering the soil, which in turn covers the seed.

The basis of these classifications was described by Baker (1976a, b, c) and Baker *et al.* (1996), who observed that, where an intermittent mulch/soil cover
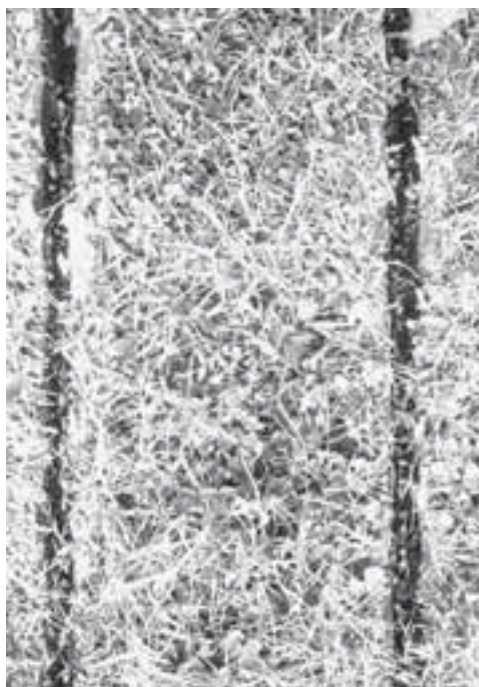
Fig. 5.1. Visible seed in Class I no-tillage slot cover (from Baker *et al.*, 1996).

Fig. 5.2.   An example of Class II no-tillage slot cover (from Baker *et al.*, 1996).

Fig. 5.3.   An example of Class IIIa no-tillage slot cover (from Baker *et al.*, 1996).

(Class IIIa) occurred under dry conditions, seedlings were seen to emerge from under a flap of dead turf (mulch) or even a piece of random residue and soil, but had not emerged from where the seed cover was confined to loose soil alone or where there was no cover at all. This suggested that loose soil may not have been the ultimate seed cover as had been previously assumed.

Fig. 5.4. An example of Class IV no-tillage slot cover in heavy standing wheat stubble and scattered straw (from Baker *et al.*, 1996).

Fig. 5.5. An example of Class IV no-tillage slot cover in sparse close-growing weeds. Note the replacement and layering of whatever residue is available in its original position and the absence of soil inversion after passage of the drill. (From Baker *et al.*, 1996.)

In fact, some engineers and agronomists continue to mistakenly assume, even today, that the best cover for seeds is loose soil (Class II). This assumption comes from what has been provided in a tilled seedbed for centuries. Residues do not exist to any degree on well-tilled soils. Generally, they have been buried or burnt prior to tillage.

The only other resource available for covering in addition to clean, loose soil is perhaps a press-wheel effect to provide slightly compacted soil, but even the benefits of that are dubious. So loose soil has been regarded as the 'ultimate cover', at least in a tilled soil.

Based on the 'loose-soil-is-best' assumption, some engineers therefore postulated that all that was needed for no-tillage was to till the soil in a series of strips and sow seed into the tilled strips as you would in a generally tilled soil, but, in this case, leaving the rest of the seedbed untilled between the strips. This is one form of strip (or zone) tillage, which has been described previously in Chapter 4.

Unfortunately, this simplistic view has no scientific basis and it is now known that it destroys several of the very special resources close to the seed that most untilled soils have, such as a mulch covering, an unbroken macropore system within the seed zone and an equilibrium soil humidity near 100%.

The Role of Soil Humidity

The atmosphere in the macropores within an untilled residue-covered soil has an equilibrium humidity of very near 100% (Scotter, 1976) at almost all moisture levels down to 'permanent wilting point', which is when a soil is too dry for plants to survive. In fact, it is 99.8% even at wilting point (1500 kPa tension). In no-tilled seeding, the soil is only broken at the surface by

strips (slots) where the drill or planter openers have travelled. The greatest loss of humidity from the soil to the atmosphere occurs at these broken strips (slots). The aim, therefore, of drilling into dry soils should be to create slots that do not encourage loss of humidity from these zones, since they are also the zones where the seeds are placed, which require moisture to initiate plant growth.

The classification of covers listed above is arranged in order of ascending humidity retention. A 'complete' (70% or greater) mulch/soil cover (Class IV) retains more humidity than an intermittent mulch and soil cover (30 to 70% residue – Class III), which is better than loose soil (less than 30% – Class II), which itself is better than no cover at all (Class I).

Choudhary (1979) and Choudhary and Baker (1981b) measured the daily loss of relative humidity (RH) from a range of different slot shapes under controlled dry conditions with constant temperature. They used the average daily RH loss for the first 3 days following seeding to compute an index value for the ability of a slot to retain humidity, moisture vapour potential captivity (MVPC).

MVPC = 1/(average 3-day RH% loss)

Table 5.1 lists results from two separate experiments in which Choudhary placed a small humidity probe in positions that would normally be occupied by the seeds within drilled slots in a dry soil. Undisturbed soil bins (weighing 0.5 t each) were placed within climate-controlled rooms at a

Table 5.1. Effect of no-tillage slot shape and cover on slot drying rates and MVPC.

	V-shaped slot (Class I cover)		U-shaped slot (Class II cover)		Inverted-T-shaped slot (Class IV cover)	
	Daily loss of RH%	MVPC	Daily loss of RH%	MVPC	Daily loss of RH%	MVPC
Experiment 1	4.23%	0.24	2.78%	0.36	2.34%	0.43
Experiment 2	3.13%	0.32	2.03%	0.49	1.02%	0.98
Mean	3.68%	0.28	2.41%	0.43	1.68%	0.71

MVPC, moisture vapour potential captivity = 1/(average 3-day RH% loss).

constant ambient temperature and constant RH of 60%.

Relative humidity is a measure of the amount of water vapour in the soil atmosphere at any one temperature. The source of supply of water vapour in the drilled slots is from the surrounding soil since its equilibrium relative humidity is always near 100%, but the rate of escape of water vapour to the atmosphere outside the soil (which is usually less than 100% RH unless it is raining or there is thick fog) is controlled by the diffusion-resistance to gases passing through the covering medium in or on the slot. For at least a few days after drilling, the soil temperatures (even in the slot) can be expected to remain at reasonably constant levels (Baker, 1976a). Therefore, measurements of relative humidity in the slots at these constant temperatures closely reflect the amount of water vapour (or the water vapour pressure) in the slot at the time.

The higher MVPC values (or lower daily losses of RH%) for Class IV covers indicate that such a slot had a higher potential to retain in-slot water vapour than Class II cover, for example, which itself had a higher water vapour retention and lower daily loss of RH% than Class I cover. The Class IV cover in these experiments was, in fact, 65% better than Class II and 154% better than Class I in retaining in-slot humidity. No Class III cover was included in this experiment.

The effects of moisture transfer from the slot micro-environments was also studied by varying the overlying air humidity at a constant temperature (Choudhary, 1979; Choudhary and Baker, 1980, 1981b). The humidity within the slots increased differently as the ambient RH was raised from 60% to 90%. Those slot shapes that increased most rapidly with a rise in ambient humidity will obviously decrease (dry) most quickly after sowing and be less favourable to seed germination and plant establishment. The most rapid change was in the open V-shaped slots (Class I cover), which increased at the rate of 8% RH per day, followed by the U-shaped slot (Class II cover), followed by the inverted-T-shaped slot (Class IV cover), which increased by only 1% RH per day.

For the inverted-T-shaped slot (Class IV cover), the rate of re-moistening was about the same as its rate of drying (i.e. approximately 1% RH per day), but for the V-shaped slot (Class I cover) the rate of re-moistening was about twice that of its drying. This confirmed that Class I cover had done little to isolate the slot micro-environment from changing ambient conditions, while Class IV cover had effectively isolated the slot from such climatic changes and retained a highly humid slot atmosphere throughout.

From a practical point of view, if seeds are sown into a favourable soil and the following week is dominated by hot dry winds, a slot that might have presented an ideal habitat for the seeds at the time of sowing can soon turn into a hostile environment unless the slot is protected from such climatic changes by adequate slot cover. Choudhary and Baker (1982) showed that no-tillage slots with Class IV cover allowed seed germination and seedling emergence from soils that were otherwise too dry to germinate seeds sown by either conventional tillage or with other no-tillage openers and slots.

A field experiment in Manawatu, New Zealand, before Class IV cover had been fully evaluated (Baker, 1976a, c) illustrated that loose soil (Classes II and III cover) is much better than no cover at all (Class I cover). In this experiment, a barley (*Hordeum vulgare*) crop was sown in late spring using hoe openers (U-shaped slot) in a silt loam soil with adequate moisture. One half of the sown rows was covered by pulling a bar harrow over the slots (Class IIIa cover) and the other half was left as the drill had created the slots (essentially uncovered, Class I). The period after drilling was hot, dry and windy. Eight days after sowing the Class IIIa covering had 205 plants/square metre, compared with the Class I cover, which had only 22 plants per square metre.

An experiment conducted at the same time and in the same soil showed that increased seed size did not compensate for poor covering. Where larger seeds might have

been expected to have more vigour and therefore be able to compensate for emergence difficulties, the opposite seemed to have happened under no-tillage. In this experiment a small-seeded species, lucerne (*Medicago sativa*), and a large-seeded species, maize (*Zea mays*), were substituted for barley and no-tilled in exactly the same manner. After 10 days, the small-seeded lucerne had 118 plants per m^2 under Class IIIa cover and 87 under the Class I cover. After a similar length of time the maize had 4.6 and 0.3 plants per m^2, respectively, for the two classes of cover.

While Class IIIa cover still increased seedling emergence with both the larger and smaller seeds, the increase was less with lucerne than with either maize or barley. The smaller lucerne seeds apparently had a better chance of finding themselves covered with a small piece of soil or mulch, which produced a favourable micro-environment for them, even in a Class I situation, than did the larger barley seeds, which were better placed than the even larger maize seeds in this respect.

A few days after the measurements of this experiment, rain ensured that all seeds germinated in all three of the experiments and the differences between treatments disappeared. Thus, the effects of cover were only important when the soil was dry or drying, although, as described in Chapter 7, cover is also important in wet conditions for other reasons.

As further evidence of the importance of cover in both wet and dry soils, Table 5.2 summarizes the 'best' and 'worst' treatments of 30 experiments conducted in New Zealand between 1971 and 1985. Each experiment, amongst other things, compared the effects of different openers and classes of cover under different soil moisture conditions on seedling emergence of a range of crops (Baker, 1979, 1994).

There are several clear trends to be seen in the Table 5.2 data, and the experiments are grouped accordingly. The first is a tendency towards improving seedling emergence with Classes III and IV covers, where surface residues were present and the soils were either very dry (experiments 1–12)

or very wet (experiments 25–30). As the moisture conditions became more optimal (experiments 13–18) and/or when surface residues were not present (experiments 19–24), the difference between the classes of cover generally became less or non-existent.

Perhaps just as important was the magnitude of some of the differences. Two- to 14-fold differences are rare in agricultural experimentation, suggesting that slot shape and cover have a major influence on the reliability and success of no-tillage practices, a fact not formerly recognized or reported. Even a ratio of 1.2 : 1 represents a 20% advantage for the 'best' treatment.

It is also notable that, where Classes I and II covers were included in the comparisons, they were almost invariably classed either as the 'worst' treatment or as 'no better than' the other treatments. They seldom outperformed any other treatment, the exceptions being in two very wet soils without residue, where seedling emergence was low with all of the openers compared. On the other hand, Classes III and IV cover were never bettered by any other treatment in the presence of surface residues in wet, optimum or dry soils.

The Table 5.2 data include only the 'best' and 'worst' treatments for simplicity. Comparisons of other intermediate treatments between these two extremes are not shown. Almost invariably, however, Class IV cover produced greater seedling emergence than Class III cover, which in turn outperformed Class II cover, especially in dry conditions. More detailed descriptions of these comparisons are given in Chapters 6 and 7.

Methods of Covering Seed Slots

There are several principles involved in covering slots after the passage of no-tillage openers, and these are often combined with pressing to obtain soil–seed contact. These methods are:

1. Squeezing – attempting to move soil sideways into the slot by a wedging action to cover and to obtain soil–seed contact.

Table 5.2.   Effects of slot cover on seedling emergence in 30 experiments.

	Year	Soil[a]	Crop	Soil moisture and residue status[b]	Best and worst treatments and classes of cover (best) : (worst)[c]	Ratio of seedling emergence counts (best) : (worst)
1	1979	S/L	Wheat	V. dry	(R) inv. T/C (IV) : t.d. V/C (I)	14 : 1
2	1971	S/L	Maize	Dry	(R) hoe U/C (III) : hoe U (I)	14 : 1
3	1971	S/L	Barley	V. dry	(R) hoe U/C (lll) : hoe U (I)	9.5 : 1
4	1972	S/L	Barley	V. dry	(R) inv. T/C (IV) : hoe U/C (II)	6 : 1
5	1979	FS/L	Wheat	V. dry	(R) inv. T/C (IV) : t.d. V/C (I)	5.5 : 1
6	1976	FS/L	Wheat	Dry	(R) inv. T/C (IV) : t.d. V/C (I)	3 : 1
7	1971	S/L	Kale	Dry	(R) hoe U/C (III) : hoe U (I)	2 : 1
8	1979	S/L	Wheat	V. dry	(R) inv. T/C (IV) : t.d. V/C (I)	1.7 : 1
9	1979	FS/L	Wheat	Adeq.	(R) inv. T/C (IV) : t.d. V/C (I)	1.6 : 1
10	1979	S/L	Lucerne	V. dry	(R) hoe U/C (III) : hoe U (I)	1.4 : 1
11	1979	S/L	Wheat	V. dry	(R) inv. T/C (IV) : t.d. V/C (I)	1.3 : 1
12	1979	S/L	Wheat	Dry	(R) inv. T/C (IV) : t.d. V/C (I)	1.2 : 1
13	1978	S/L	Wheat	Adeq.	(R) inv. T/C (IV) : t.d. V/C (I)	no diff.
14	1978	S/L	Lupin	Adeq.	(R) inv. T/C (IV) : t.d. V/C (I)	no diff.
15	1979	S/L	Wheat	Adeq.	(R) inv. T/C (IV) : t.d. VN (I)	no diff.
16	1979	S/L	Wheat	Dry	(R) inv. T/C (IV) : t.d. V/C (I)	no diff.
17	1979	S/L	Wheat	Adeq.	(R) inv. T/C (IV) : t.d. V/C (I)	no diff.
18	1979	S/L	Wheat	Adeq.	(R) inv. T/C (IV) : t.d. V/C (I)	no diff.
19	1985	S/L	Barley	Adeq.	(NR) inv. T/C (IV) : t.d. V/C (I)	no diff.
20	1985	S/L	Barley	Adeq.	(NR) inv. T/C (IV) : t.d. V/C (I)	no diff.
21	1985	S/L	Barley	V. wet	(NR) p.t. U/C (III) : p.p. U/C (I)	4.2 : 1
22	1985	S/L	Barley	V. wet	(NR) inv. T/C (IV) : t.d. V/C (I)	1.7 : 1
23	1985	S/L	Barley	V. wet	(NR) t.d. V/C (I) : inv. T/C (IV)	1.6 : 1
24	1985	S/L	Barley	V. wet	(NR) t.d. V/C (I) : inv. T/C (IV)	1.2 : 1
25	1985	S/L	Barley	V. wet	(R) inv. T/C (IV) : t.d. V/C (I)	4.4 : 1
26	1985	S/L	Barley	V. wet	(R) inv. T/C (IV) : t.d. V/C (I)	2.9 : 1
27	1985	S/L	Barley	V. wet	(R) inv. T/C (IV) : t.d. V/C (I)	2.7 : 1
28	1985	S/L	Barley	V. wet	(R) inv. T/C (IV) : t.d. V/C (I)	2.5 : 1
29	1985	S/L	Barley	V. wet	(R) inv. T/C (IV) : t.d. V/C (I)	1.5 : 1
30	1985	S/L	Barley	V. wet	(R) inv. T/C (IV) : t.d. V/C (I)	1.4 : 1

[a]Soil types: S/L = silt loam; FS/L = fine sandy loam.
[b]Soil moisture and residue status: V. dry = Very dry; Adeq. = Adequate: V. wet = Very wet.
[c](R) = surface residues present; (NR) = no surface residues present; (I), (II), (III) and (IV) = the classes of cover in each experiment. Drilling and covering treatments: t.d. V = triple disc opener, vertical V-shaped slot, not covered; t.d. V/C = triple disc opener, vertical V-shaped slot, covered; hoe U = hoe opener, U-shaped slot, not covered; hoe U/C = hoe opener, U-shaped slot, covered; inv. T = winged opener, inverted-T-shaped slot, not covered; inv. T/C = winged opener, inverted-T-shaped slot, covered; p.t. U = power till opener, U-shaped slot, not covered; p.t. U/C = power till opener, U-shaped slot, covered; p.p. U = simulated punch planter, U-shaped holes, not covered; p.p. U/C = simulated punch planter, U-shaped holes, covered.
Sources: Experiments 1, 5, 8, 9, 11, 12, 15, 16, 17 and 18 (Choudhary, 1979); Experiments 2, 3, 4 and 10 (Baker, 1976a); Experiment 6 (Baker, 1976b); Experiment 7 (Baker, 1971), Experiments 13 and 14 (Mai, 1978); Experiments 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29 and 30 (Chaudhry, 1985).
Note: In all experiments where the slots were covered, the covering material was the best available as provided by the shape of the slot and opener action.

2. Rolling – pressing vertically on the soil alongside the slot with a roller of some description.

3. Pressing – selectively pressing on or in the slot zone itself, including non-vertical rolling or pressing mainly to obtain seed–soil contact, but can also include an element of covering.

4. Scuffing – scraping up loose surface material from the slot zone and directing it to fall back into the slot, solely for covering.

5. Deflecting – discretely deflecting soil from a particular part of the slot, solely for covering.

6. Tilling – loosening the ground behind the opener, usually so that it can be more easily manipulated by one of the other devices previously listed.

7. Folding – folding soil and/or residue back from whence it came, solely for covering.

Often two or more of these actions are combined in one covering/pressing device or system.

To a casual observer, there might not seem to be much difference between the various actions described above. However, a description of the advantages and disadvantages of each principle will illustrate why cover and, to a lesser extent, pressing are such an important factor in reducing the risks associated with no-tillage.

Squeezing

Squeezing is the principle applied by many manufacturers of vertical double disc openers (see Chapter 4). It usually involves pressing down with a V-shaped wheel alongside the slot after its formation in such a manner that the mass of soil is pushed bodily sideways without actually loosening it. The aim is to squeeze the slot closed by moving the soil back from whence it came. Figure 4.7 illustrates squeezing wheels behind double disc openers. The advantages are that such wheels are simple, require little adjustment and are not inclined to block with residue.

The disadvantages are that there is almost as much downforce required on the pressing wheels as was needed on the opener to create the slot in the first place,

adding to the weight requirements of the drill; the pressing action further compacts the soil next to the seed; its ability to close the slot is highly dependent on soil plasticity and moisture content; any useful effect may be undone quickly if the soil dries and shrinks after pressing. Slots made in soils that do not squeeze easily might not be adequately closed, although with soils of this nature there is little else that can be done to remedy the situation. With soils in which the slot can be squeezed back together, there is a risk of so tightly trapping the seeds with compacted soil that emergence of seedling shoots is restricted.

Rolling

General rolling of a field after drilling is often undertaken in an attempt to produce some of the squeezing action described above in a random manner, without directing the action to any specific zone. It works best where slot formation results in considerable hinged upheaval of the soil such as with hoe openers and some simple inverted-T-shaped openers. The vertical forces from the roller tend to squash any raised ridges of soil downwards and, to a limited extent, sideways. Since most of the raised portions of soil will be alongside the slots, a degree of covering often results, although, as with squeezing, the final result is highly dependent on soil moisture content and plasticity.

Both flat and ringed ('Cambridge') rollers are used. The problem with ringed rollers is that the points of the rings apply more pressure than the shoulders. If the point of a ring happens to coincide with the centre of a sown row it may help to bury the seed too deeply or at least it may seal the exit zone so tightly as to restrict seedling emergence. For these reasons flat rollers are preferred to 'Cambridge' rollers.

The main advantage of rollers is that they are generally readily available implements and easy to use, and their downforces are derived from their own weight rather than the drill. They also leave a relatively flat finish to the field, which might be important at harvesting.

The disadvantages are that covering must be done as a separate operation and that much of the loose soil and debris is not adequately moved sideways into the slot zone but is instead 'trampled' down where it lies, in which case it might not contribute to covering at all. This latter disadvantage is more of a problem with hoe openers than with simple inverted-T-shaped openers, because the latter hinge up a flap of soil rather than bursting it out bodily sideways in the manner of hoe openers.
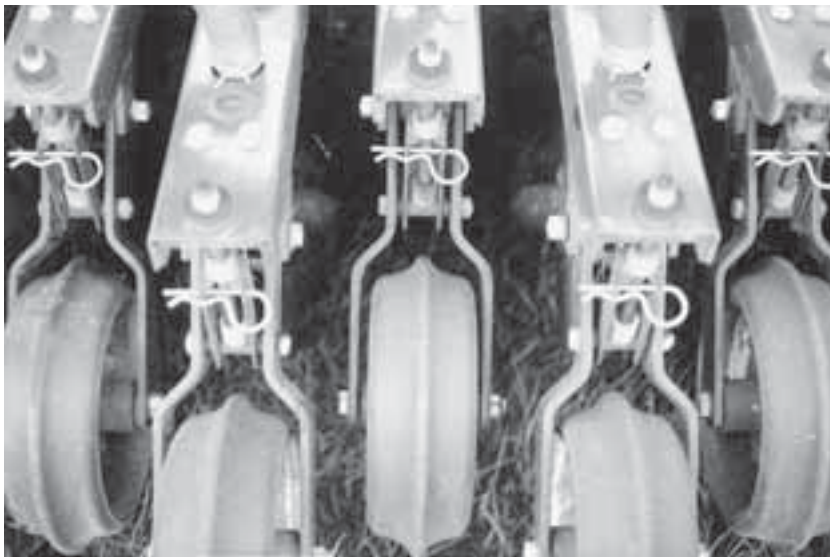
Pressing

Pressing is really rolling in a discrete zone and perhaps at a discrete angle in or on top of the slot. The slot can be pressed either after it has been covered by some other means (e.g. scuffing) or prior to the covering action. The object of pressing alone is to effect the covering action and it is particularly useful with slanted double disc openers. Pressing in association with another covering device improves soil–seed contact, but there is little scientific evidence to show that this results in an improvement in seedling emergence under no-tillage except perhaps by improving the consistency of seeding depth (Choudhary, 1979; Choudhary and Baker, 1981a).

Pressing before covering, on the other hand, has been shown to be of major benefit with some openers such as hoe and vertical double discs. Few manufacturers, however, have seen fit to provide press devices that act on the seed before covering of the slot. Figure 5.6 illustrates a ribbed press wheel designed to press in the base of the slot while simultaneously rolling on the undisturbed soil alongside. Figure 5.7 shows a packing device designed to firm the seed into the base of the slot at the same time that covering takes place.

The advantages of pressing are that it usually involves a wheel (or pair of wheels) that can double as a depth-control device. This double function, however, is not easy to achieve if the press wheel operates in the base of a slot, since the wheel then registers on a soil surface that has already been created by the opener and thus may have little reference to the true surface of the soil. On the other hand, pressing before covering does more to counteract the disadvantages

Fig. 5.6.   A press wheel with central rib, which is designed to press in the base of the slot at the same time as it locates on the soil surface (from Baker *et al.*, 1996).

Fig. 5.7. A shank-type opener with packing device to firm seeds into the base of the slot at the same time as covering takes place.

of U- and vertical V-shaped slots than any other known method (Choudhary, 1979; Choudhary and Baker, 1981a). The effect seems to be to press the seeds into the undisturbed soil at the base of the slot so that their emerging roots do not need to negotiate the slot wall in order access soil water.

The disadvantages are that pressing alone is not always a covering action at all. It is usually done after or before covering is achieved by some other means, so two separate mechanisms are necessary. Also, because pressing after covering is easier to achieve and the press wheels are able to roll on the undisturbed soil alongside the slot and thereby achieve depth control at the same time, this has become the preferred option. It does not, however, achieve as much biologically as pressing before covering (see also Chapter 6).

Scuffing

Scuffing is probably the easiest and most effective general slot covering option that can be performed by a separate machine after drilling, regardless of the type of drill opener used. It usually involves a heavy, wide, flexible harrow of some nature, which is pulled across the ground, preferably parallel to the drill slots. The harrow scrapes up the general loose soil spilled from the slots and other

debris, and pushes this material back over the slots in a random manner. Its action depends on the untilled ground between the rows being able to support the weight of the device so that it does not cut into the soil and thereby accumulate excess soil and debris. Some of the heavy harrows used in no-tillage are therefore not applicable to tilled soils.

Various harrows have been used, ranging from chain harrows with the points facing upwards to avoid gouging seed out of the slots, truck tyres that have been split longitudinally with the cut surfaces facing downwards, oyster nets, heavy chains and short lengths of railway iron chained together. Figure 5.8 shows a bar harrow made of railway iron operating in a friable soil after a drill with hoe openers (Baker, 1970). Figure 5.9 is a plan of such a harrow, suitable for a 2.4 m wide drill.

The advantages of harrows are that they are virtually foolproof to operate, simple and inexpensive. For many slot shapes created in damp soils, harrowing is best delayed a few hours to allow some dry crumbs to develop, which can then be scraped up as friable covering material. A separate harrow is ideal for such situations.

The disadvantages are that if no crumb is formed when drilling, for example, with vertical double disc openers operating in a damp soil, even harrows will be ineffective to provide cover. Their use constitutes another operation, although, if a time delay is not appropriate, they can be attached behind the drill; and with severe residue they can become blocked.

A variation of scuffing and rolling is provided by spiral-caged rollers, as shown in Fig. 5.10. These devices combine the pressing effect of a roller with the scuffing effect of a harrow, since the spiral nature of the rolling ribs ensures that some sideways scuffing takes place as the roller rotates. They are easy and convenient to use but do not move as much debris and soil as a true harrow.

Deflecting

With some hoe openers, small deflecting devices are incorporated on the rear of the

Fig. 5.8. A simple bar harrow for covering no-tillage slots (from Baker *et al.*, 1996).
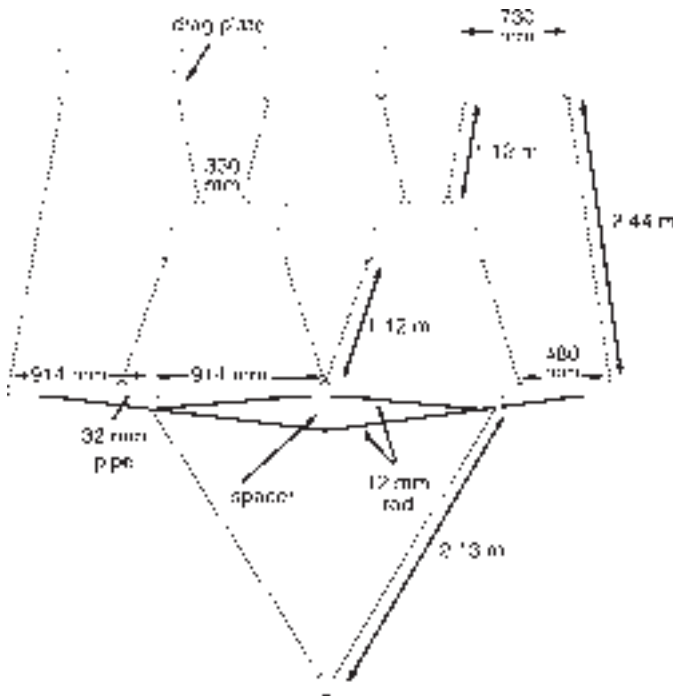
Fig. 5.9. Plan for a simple bar covering harrow (from Baker, 1970).

opener so as to scrape a small slice of soil from the slot wall and allow it to fall on to the seed and/or fertilizer. One of the purposes of doing this has been to attempt to get a soil covering over a deposit of fertilizer in the base of the slot before seed is deposited on top of the soil, thus separating them vertically within the slot (Hyde *et al.*, 1979, 1987).

Fig. 5.10. A spiral-caged roller for covering no-tillage slots.

Unfortunately, the function of any fixed device, such as an internal scraper of this nature, is highly dependent on the position of the scraper relative to the slot walls. Since the slot walls themselves are never in exactly the same place in two different soils, or even in the same soil at different moisture contents or operating speeds, either the scrapers have to be manually adjusted for each new soil condition or the functional ability of the device will vary quite widely with the conditions. While successful deflectors facilitate vertical separation of seed and fertilizer in the slot, stationary scrapers often collect residue and cause blockages.

Tilling

Because of the difficulty of moving soil that has been squeezed sideways back in the opposite direction, some openers attempt to loosen the soil alongside the slot with the aid of spiked wheels or discs. Often, spiked discs are arranged alongside angled press wheels so that the loosening and

reverse-squeezing actions are combined into one, such as those shown in Fig. 5.11.

The advantages are that the soil is more easily moved, and, because it is in a loosened state, the risk of further compaction, particularly over the seedling emergence zone, is reduced. The disadvantage is that any disturbance of this nature partly destroys the integrity of the residue and soil layering, and at best results in a random mixture of soil and residue as the covering medium.

Folding

Folding of material back over a slot presupposes that a horizontal slot has been created in a manner that hinged the original covering material up in the first place. Alternatively, the slot may have been created so that the original covering material has been displaced bodily sideways without inversion and mixing, in a manner that allows it to be retrieved and replaced as if it had not been moved in the first place.

Realistically, this applies only to inverted-T-shaped horizontal slots, slanted

Fig. 5.11.   A pair of combined spiked discs and angled press wheels for covering no-tillage slots (from Baker *et al.*, 1996).

double disc openers and perhaps those angled dished disc openers that have a positive tilt angle. Even with inverted-T openers, the folding feature is more a function of how the slot is created than the action of the covering device. For example, the uplifted flaps of most inverted-T-shaped slots, when created in pasture, can be folded down again either by a scuffing harrow or by press wheels. Press wheels are more tolerant of different soil and pasture conditions, and are more predictable than scuffing harrows, but they need to be angled to combine the folding and pressing functions.

In non-pasture soils such as arable soils with loose or lying residue, the folding function can only be realistically performed by press wheels. It is even possible to refine the folding function sufficiently to allow stratified soil layers, e.g. a thin dry dust mulch that overlies more moist soil, to be replaced more or less in the same order that they were in before passage of the opener. Figure 4.27 and 4.29 show a pair of folding wheels, which also function as depth-gauging wheels, on a disc version of a winged opener.

The advantages of folding are that the covering function is predictable and reliable and usually does not require adjustment of opener components to cope with different soil or residue conditions. It can also result in complete mulch and soil cover (Class IV), so long as there was a mulch covering the soil in the first place.

The disadvantages are that excess pressure from press wheels on a damp pasture flap might close the slot so tightly as to make it difficult for seedlings to emerge. Since this is a function of the downforce applied to the openers, it is easily adjusted in the normal course of setting up a no-tillage drill.

Summary of the Role of Slot Cover

1.   There are four distinguishable classes of slot covers, ranging from no cover (Class I), loose soil (Class II), soil and a small amount of mulch or residue (Class III), to complete (greater than 70%) soil and mulch (Class IV).
2.   In Class III, the small amount of mulch or residue in the covering medium may be

either in intermittent clumps (Class IIIa) or a thoroughly mixed combination of residue and soil (Class IIIb).

3. Class I–IV covers are ranked in ascending order of their abilities to retain slot water vapour.

4. The benefits of covering in terms of seedling emergence are ranked in ascending order of Classes I–IV.

5. Principles of covering slots and/or obtaining soil–seed contact involve squeezing, rolling, pressing, scuffing, deflecting and/or folding soil and/or mulch.

6. Some covering methods involve separate operations and machines that are used after drilling, in which case the weather and soil plasticity after seeding become important.

7. Other covering methods involve simultaneous functions by the openers themselves, in which case the nature and speed of slot formation become important.

8. Vertical double disc and triple disc furrow openers and punch planters usually produce Class I or II cover.

9. Slanted double and single disc openers and winged openers are capable of producing Class IV cover.

10. Hoe, angled vertical flat disc and angled vertical dished disc openers tend to produce Class II or IIIa cover, depending on the speed of travel.

11. Power till openers tend to produce Class IIIb cover, regardless of speed.

12. Angled dished disc openers sometimes produce Class IV cover at slow speeds.

13. The disc versions of winged openers are designed to produce Class IV cover regardless of speed, soil moisture conditions or residue conditions.

6 Drilling into Dry Soils

C. John Baker

———————————

A dry untilled soil has more potential to germinate seeds and allow seedlings to emerge than a dry tilled soil; but very few no-tillage openers are capable of harnessing that potential.

Most of the world's agriculture involves growing plants in soils that become dry at some point in their growing cycles. If farmers could predict exactly when the soil was going to become dry, they would plan accordingly. In many climates an approximate idea of the onset of rain allows farmers to match the planting of crops to expected weather patterns. These matchups, however, are seldom accurate to better than a few weeks, if that.

When sowing seeds into untilled soils, a matter of a few days either way may make the difference between successful crop establishment or failure. This is not to say that untilled soils are less forgiving than tilled soils; indeed, most have the potential to be more forgiving. The problem is that most people have not yet learned how to harness that tolerance to their advantage.

With little guarantee that it will rain on a particular day after drilling, farmers are unlikely to attempt to drill seed into an already dry soil. On the other hand, if a farmer drills seed into a soil that appears to have adequate moisture but then finds the next week dominated by hot dry winds, what had been an optimum environment for seeds may soon become a hostile environment.

None the less, so long as there is sufficient weight for penetration of the drill openers and sufficient energy to pull the machine through the soil, it is possible to operate a no-tillage drill in a dry soil. This contrasts with wet soils (see Chapter 7), where operation of machinery is often simply not possible.

How Soils Lose Moisture

To understand the tolerance of untilled soils to dry weather, it is necessary to distinguish between an untilled soil that is covered with a mulch and an untilled soil that has a bare surface. It is also important to compare the ways in which tilled and untilled soils transport water to the surface for evaporation.

A tilled soil will lose moisture more rapidly than an untilled soil, at least initially. But because of the increased porosity of tilled soils, the loss of moisture from the upper zones will not be quickly replenished from deeper zones. The capillary rise of water is poor through the large voids and pores that result from tillage.

Because of this, a dry layer may be formed at the top of tilled soils. In some climates a dry dust mulch layer is deliberately formed by repeatedly tilling the surface layer of soil until it becomes a super-dry dust with very low moisture and thermal conductivities. The rationale behind such a practice is that, in the absence of any other form of surface mulch, there is a net saving in moisture loss by sacrificing a small amount of water to form a 'dust mulch' in the interest of conserving the greater amount of water lying beneath it.

An untilled soil, on the other hand, will usually have a well-developed capillary system from the surface to some significant depth, which acts as a continuous 'wick', transporting water upwards during periods of drying at the surface. This internal transport system will become more effective with time as soil structure improves. Thus, while the initial loss of moisture will be slower from the surface of a bare untilled soil than from a tilled soil because the surface is smoother and therefore does not create as much air turbulence or allow air to enter as easily, it may continue supplying water to the surface for evaporation for a much longer time than a tilled soil that is covered with a dust mulch. This, then, is where the presence of an organic residue mulch and the action of the drill openers that operate in an untilled soil become important.

The Role of Vapour-phase Soil Water

All soils contain both liquid-phase water and vapour-phase water in the form of humidity. The equilibrium relative humidity of the pore spaces between the particles of undisturbed soil is virtually 100% at all liquid moisture levels down to permanent wilting point (Scotter, 1976). The permanent wilting point (PWP) is the point where the soil is considered too dry to sustain most plant life. The status of liquid soil water is often expressed as the tension by which water films are held by the soil particles. At PWP this tension is −15 bar.

The important point is that plants wilt and die at PWP and will not recover if watered again. However, it is important to remember that, even at that moisture content, the soil macropores contain 99.8% relative humidity.

Like hair on the skin of an animal, an organic mulch traps a layer of still air close to the soil surface, which slows down the exchange of water vapour between the soil and the atmosphere. Most importantly, the humidity within that mulch layer will remain much higher than the atmosphere above it, unless, of course, it is raining or the atmosphere is at a high humidity anyway.

On a hot, dry day, for example, if one were to take a rapid-response humidity probe and carefully slide the probe under a single large leaf lying on bare untilled soil without moving the leaf, there would be a noticeable rise in the humidity reading as the probe moved under the leaf and then a drop when it was removed. The same thing would happen under a piece of plastic or paper. This demonstrates that a localized high-humidity zone is possible under a mulch at the soil surface. This mulch zone can be quite small in area and unaffected by another un-mulched zone nearby that has a much lower humidity. This is a very important phenomenon and is one of the major differences between no-tillage openers.

Every farmer in the world can recognize whether or not a tilled soil has sufficient liquid-phase water for germination. The judgement is usually made on the basis of the colour of the soil – darker-coloured soil is wetter – or the temperature of the soil – colder soil is wetter.

Soil humidity is rarely accounted for in a tilled soil. Nor should it be. Unless the soil humidity is at least 90%, germination will mainly occur through uptake (imbibition) of liquid-phase water from the soil by the seed (Martin and Thrailkill, 1993; Wuest, 2002). The humidity in the surface layers of a tilled soil is likely to approach 90% only on a very humid day or immediately after rain. As will be explained below, the humidity in the drilled slot of an untilled soil is even more important than in the general soil matrix (Choudhary, 1979; Choudhary and Baker, 1981a, b).

Response / Opener	Triple (double) Disc V	Hoe U	Winged Opener ⊥
Germination	✔	X	✔
Subsurface seedling survival	XX	✔	✔✔
Seedling emergence	✔XX	✔X	✔✔✔
Loss of humidity from slot	High	Medium	Low
Covering the seed	✔X	✔✔	✔
Pressing on cover	X	X	X
Pressing on seed before covering	✔	✔✔	X

Fig. 6.1. Summary of the responses of contrasting no-tillage slot shapes to dry soil conditions. (✔ = good, X = poor.)

Figure 6.1 illustrates what generally occurs when seeds are drilled into dry untilled soils with vertical double disc openers (V-shaped slot, Class I cover); hoe openers (U-shaped slot, Class II or III cover); and winged openers (inverted-T-shaped slot, Class IV cover). The following explanations are relevant for each line on Fig. 6.1.

Germination

Germination can occur from uptake of either liquid-phase water or vapour-phase water (humidity), or both. For liquid-phase water uptake to occur the seed must have physical contact with water-bearing soil by adequate soil–seed contact.

When seed is wedged in the base of a V-shaped slot (vertical or slanted) in a dry soil, the transfer of water from the soil to the seed is generally adequate, even though the contact zones with each wall of the slot may be relatively small (Fig. 6.2). The smooth, and often compacted, slot walls are a ready source of liquid-phase water, which is otherwise scarce in a dry soil. Thus germination within a V-shaped slot in a dry soil (Class I cover) can be 'good'.

With U-shaped slots, there is usually more loose soil within the slot, which also has a broader base for the seed to lie upon (Fig. 6.3). These two factors cause poor transfer of scarce liquid-phase moisture to the seed. Even when loose soil covers the slot and seed, there is little liquid-phase moisture in this covering medium because of its loose nature. It remains dry and acts in
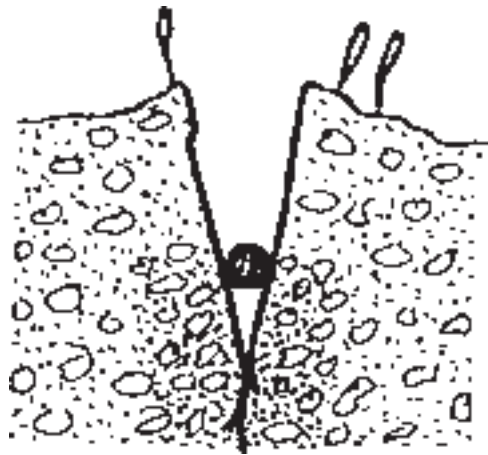

Fig. 6.2. The position a seed takes in a vertical V-shaped no-tillage slot.
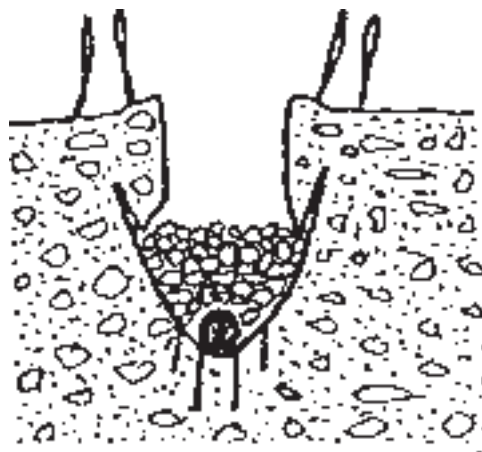

Fig. 6.3. The position a seed takes in a U-shaped no-tillage slot.

a similar manner to a dust mulch, as described above. Thus germination within a U-shaped slot in a dry soil (Class II or III cover) is often 'poor'.

With inverted-T-shaped slots, the supply of liquid-phase water to the seed is little different from that with U-shaped slots (Fig. 6.4). The Class IV cover, however, results in the seed being surrounded by vapour-phase water of 90–100% humidity (see Chapter 4). The seeds take a little longer to germinate than where liquid-phase water is available, but eventually a high germination count results. Thus germination within an inverted-T-shaped slot in a dry soil (Class IV cover) is usually 'good'.

Subsurface Survival

The most overlooked and under-studied stage of development of no-tilled seedlings is the time between germination and when the juvenile plants finally emerge from the soil. All of this period is spent beneath the soil. To remain alive the seedlings derive nutrients from their seed reserves and moisture through the embryonic roots, which appear at the time of germination.
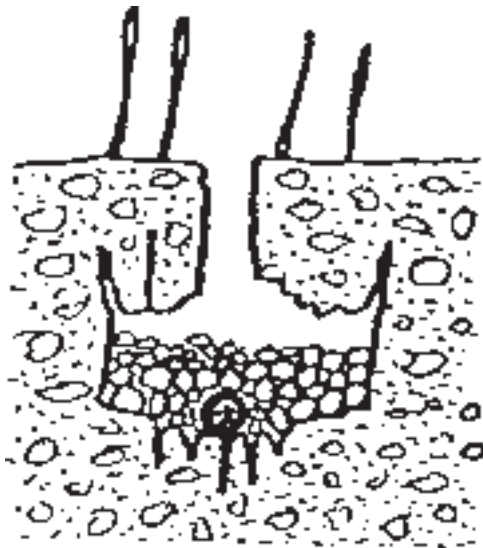
Fig. 6.4. The seed position in an inverted-T-shaped no-tillage slot.

These pre-emerged plants will not have developed the ability to photosynthesize food and energy from the sun's rays. There is only a limited need for them to draw water from the dry soil while they are beneath the surface, because it is mainly the sun that stimulates transpiration from plants. The subsurface seedlings, however, do respire (breathe), consuming moisture, and there may be subsurface water loss where the soil humidity, and therefore water vapour pressure, is lower than the corresponding water vapour pressure within the embryonic plants, which results in a diffusion loss through the cell walls.

Together with respiration, the end result is a tendency for subsurface seedlings to desiccate (dry out) unless they have an available source of soil water. With vertical V-shaped slots (Class I cover), many of the new seedlings become desiccated and die. Often they see sunlight very soon after germination because of the absence of covering material in the slot. But, even with Class II cover (loose soil), they may still die. The reason often is that the embryonic roots have to negotiate and penetrate the compacted slot walls before they can access liquid-phase water from the surrounding soil.

Since the slot walls are nearly vertical and there is little resistance against which the roots can base penetration forces, other than the weight of the seed, the roots tend to have difficulty penetrating the slot walls and instead spread sideways along the slot. The result is that seedlings after germination receive a poor water supply. Seedlings cannot stand the strong desiccation demand from a soil humidity that usually, at best, remains in the 60–80% range in vertical V-shaped slots. Therefore, many subsurface seedlings die before emergence in a vertical V-shaped slot in a dry soil.

It is useful to contrast this situation with a fully tilled dry soil. In a tilled dry soil, seeds are placed in a loose and friable medium. First, this medium probably does not transport enough liquid-phase water to the seed to bring about germination. But, even for those seeds that do germinate, there is no compacted slot wall for embryonic roots to penetrate. So subsurface seedling

deaths in tilled soils are rare, similar to U-shaped no-tillage slots.

With U-shaped slots (Class II or III cover), although germination is often poor, the roots of those seedlings that do germinate have less trouble penetrating the uncompacted and broader base of the slots. If the slot can be covered to Class II or Class III standard, i.e. at least loose soil or a mixture of soil and residue, the likelihood of desiccation of subsurface seedlings is also reduced. Humidity is likely to remain in the 70–90% range. The result in U-shaped slots in a dry soil is that a reasonable percentage of the subsurface seedlings survive, although there may not be many that germinate until rain (or even dew) arrives, which means that seedling emergence may be spread over a long time.

Figures 6.5 and 6.6 show four wheat plants that were extracted from dry no-tillage plots in Australia. In Fig. 6.5, the plants are oriented so that the slot is running in the same direction as the wire fence (i.e. across the field of vision). The two plants on the left were sown with a vertical double disc opener (V-shaped slot) and the two on the right were sown with a wide, hoe-type opener (U-shaped slot). Root development

along each of the rows is approximately equal for all four plants (i.e. for both slots).

In Fig. 6.6, all four plants have been rotated 90° and are now oriented with the drill rows running towards the camera. Clearly the roots of the plants on the left (vertical V-shaped slot) have hardly moved sideways out of the slot at all, but have stayed essentially within the slot walls. The roots of the plants on the right (wide U-shaped slot), on the other hand, have spread about as much sideways as they had lengthwise (Fig. 6.5). This illustrates the difficulty that young (and even, in this case, mature) roots have in penetrating the slot walls of some vertical V-shaped slots, compared with U-shaped slots.

With inverted-T-shaped slots (Class IV cover), humidity usually remains in the 90–100% range because of the residue-covered slot. While this will result in high (if sometimes slow) counts of germination, its most important function is that it removes most of the desiccation or transpiration stress from the subsurface seedlings, with the result that their survival rate is also high.

Embryonic root exploration out of the slot zone is no more restricted with inverted-T-shaped slots than with U-shaped slots.

Fig. 6.5.   Wheat plants from a no-tilled crop in New South Wales, Australia; slot direction is parallel to the fence (from Baker *et al.*, 1996).

Fig. 6.6. Wheat plants from a no-tilled crop in New South Wales, Australia; slot direction is towards the camera (from Baker *et al.*, 1996).
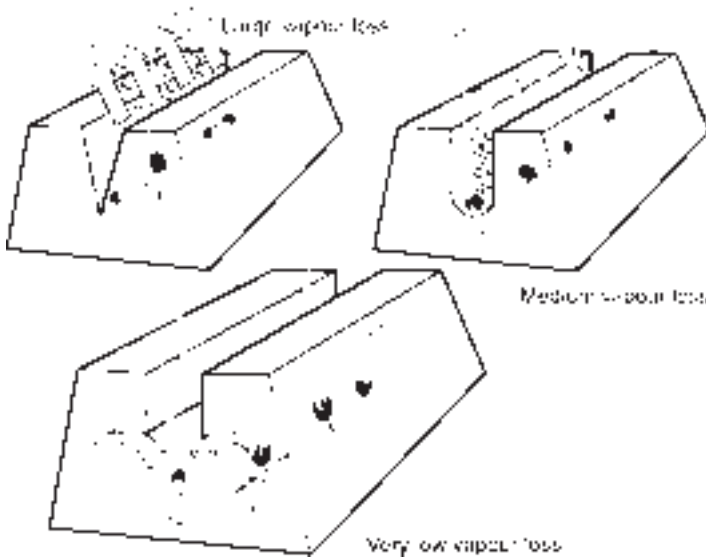
Fig. 6.7. The relative rates of loss of soil humidity from V-, U- and inverted-T-shaped no-tillage slots (from Carter, 1994).

The combined result is that, with inverted-T-shaped slots in a dry soil, most of the subsurface seedlings survive, leading to rapid and consistent seedling emergence.

Figure 6.7 illustrates the relative rates of humidity loss from the three contrasting slot shapes (Choudhary and Baker, 1994).

Scientists in New Zealand tried covering vertical V-shaped slots with strips of plastic to artificially trap water vapour in the otherwise open slots and create artificial Class IV cover (Choudhary, 1979). The humidity increased, but fungal growth soon also became evident in the slots, probably indicating that air circulation had been reduced. Therefore, nature had the perfect covering medium in the form of organic mulch and residue. Mulch breathes, as well

as trapping humidity. Plastic does not breathe, even if it traps humidity, and it is quite impractical to cover every slot drilled with plastic strips.

It is little wonder, therefore, that deciduous trees flower, set seed and drop their seeds to the ground before they drop their leaves. Nature's intention seems to have been to cover the seeds with mulch.

Seedling Emergence

The more **X**s in the total for a slot in Fig. 6.1, the less effective that slot is at promoting seedling emergence from a dry soil. Conversely, the more ✓s in the total, the better the slot.

In summary, the order of ranking with regard to dry soils is:

1. Inverted-T-shaped slots – Class IV cover – excellent germination, excellent survival and thus excellent emergence.
2. U-shaped slots – Class II or III cover – poor germination, adequate survival and thus substandard emergence.
3. Vertical V-shaped slots – Class I or II cover – excellent germination, poor survival and thus poor emergence.

Table 6.1 (Choudhary, 1979) lists typical patterns of wheat (*Triticum aestivum*) seed and seedling responses to the three slot shapes in dry soils. These results illustrate the separate mechanisms of failure of vertical V- and U-shaped slots, i.e. subsurface seedling mortality and germination failure, respectively.

With vertical V-shaped slots, seedling emergence was poor (27%), although germination had been reasonably good. Only 9% of the seeds failed to germinate, the same as for the inverted-T-shaped slot. On the other hand, a high percentage (64%) of these germinated seedlings remained un-emerged beneath the soil in the vertical V-shaped slots, and most of them died.

With U-shaped slots, although a higher percentage (51%) emerged than with V-shaped slots, 23% of the seeds had not germinated in the first place. For those that did germinate, subsurface seedling survival was reasonably good. Only 26% of the seedlings remained un-emerged beneath the soil, similar to the inverted-T-shaped slots (27%).

The distinguishing feature of the inverted-T-shaped slots was that 64% of the seeds germinated and emerged. In addition, 27% germinated and remained alive beneath the soil, awaiting rain. Only 9% did not germinate in the first place.

Figure 6.8 shows typical seedling emergence patterns of wheat, no-tilled into a dry soil under controlled dry conditions (Baker, 1976b). Clearly the seeds sown in the inverted-T-shaped slots emerged in much greater numbers (78%) than from U- (28%) or vertical V-shaped slots (26%). There was a few days' delay before the seeds in the inverted-T-shaped slot started to emerge, possibly because they were taking up vapour-phase water rather than the liquid-phase water that the other two slots were supplying; but thereafter the emergence rate was very rapid compared with the other two slot shapes.

Table 6.1. Wheat seed and seedling responses to no-tillage openers and slot shapes in a dry soil.

	Double disc opener Vertical V-shaped slot Class I cover	Hoe opener U-shaped slot Class II cover	Winged opener Inverted-T-shaped slot Class IV cover
Seedling emergence	27%	51%	64%
Germinated seeds that had failed to emerge	64%	26%	27%
Un-germinated seeds	9%	23%	9%
Total seed pool	100%	100%	100%
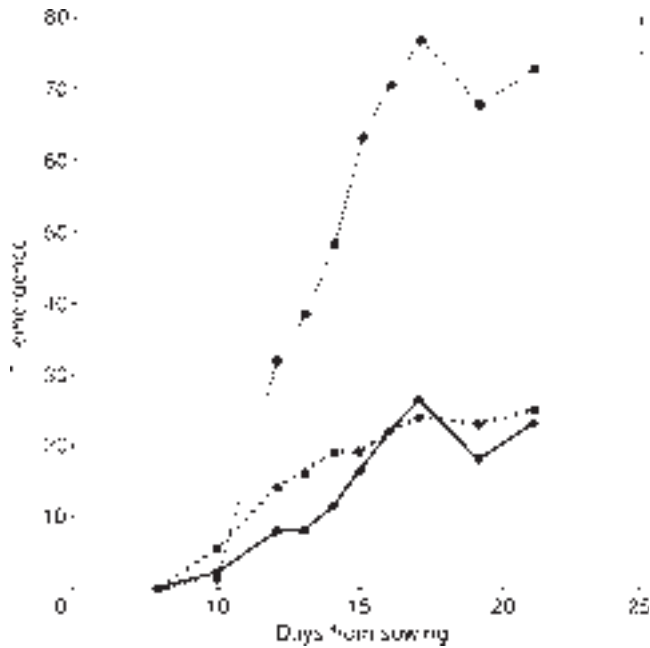
Fig. 6.8. Wheat seedling emergence patterns from V- (——), U- (- - - -) and inverted-T-shaped (·····) no-tillage slots in a dry soil (Baker, 1976b).
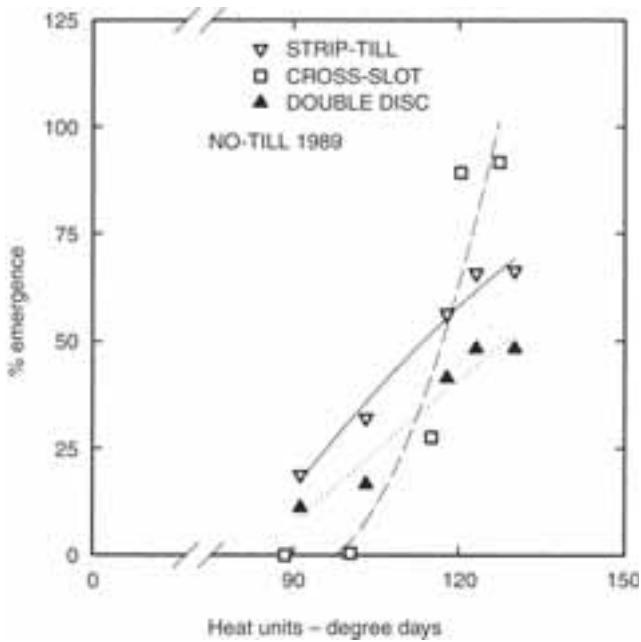
Fig. 6.9. Pea seedling emergence patterns from V-, U- and inverted-T-shaped no-tillage slots in a dry soil (from Wilkins *et al.*, 1992).

This phenomenon is also illustrated in Fig. 6.9, which shows field seedling emergence patterns of peas in a dry soil in Oregon, USA (Wilkins *et al.*, 1992). Vertical V-, U- and inverted-T-shaped slots were used, which were represented by 'double disc', 'strip-till' and 'cross-slot' openers, respectively.

Emergence from the U-shaped slots was spread over a 2–3-day period and reached a maximum of 65%, 5% better than V-shaped

slots, which otherwise spread their emergence pattern over the same length of time. Seedlings in the inverted-T-shaped slots did not start to emerge until 1–2 days after the other two slots, but then almost all of the plants came up in a single day and attained a total of 90% emergence. The evenness and consistency of emergence shown by the inverted-T-shaped slot has important consequences for eventual crop maturity and yield; and, of course, 90% emergence contributes to greater yields than 50–65% emergence.

A further experiment by Choudhary (1979), shown in Table 6.2, illustrates the effectiveness of the three slot shapes in a dry soil compared with the same soil when rewetted. The most noticeable effect was that both the vertical V- and U-shaped slots responded positively when the moisture status of the soil was raised. Their seedling emergence counts increased by fourfold and twofold, respectively. The inverted-T-shaped slots increased by only 9% because their dry soil counts were reasonably high in the first place.

As in Table 6.1, vertical V-shaped slots had a high count (72%) of un-emerged seedlings in the dry soil, which decreased only slightly (to 58%) in more moist conditions, indicating that many seedlings had already died. U-shaped slots had a relatively high count (47%) of un-germinated seeds in the dry soil, which was later eliminated altogether (to 0%) when the soil moisture level was raised, indicating that all the un-germinated seeds had remained viable. This illustrates

again that the causes of failure in a dry soil for vertical V- and U-shaped slots are quite different from one another. In the case of vertical V-shaped slots, it is failure of seedlings to survive beneath the soil, while, in U-shaped slots, it is failure of seeds to germinate in the first place. With inverted-T-shaped slots, most of the seeds had germinated even in the dry soil and about the same number as for U-shaped slots remained un-germinated beneath the soil.

The question arises as to what happens to the subsurface seedlings that have not emerged from a dry soil in field situations. The fate of such seedlings depends on two things: (i) how soon after drilling rain occurs; and (ii) how effectively the slot maintains the subsurface seedlings in a viable state awaiting that rain. The high humidity of inverted-T-shaped slots will maintain seedlings in a viable state for much longer than U-shaped slots, which are themselves better in this respect than vertical V-shaped slots. In the laboratory, germinated wheat seedlings have remained viable beneath a dry soil with Class IV cover for 3 weeks. In one field situation, however, on a very light soil of volcanic ash origin, ryegrass (*Lolium perenne*) seedlings survived beneath the surface of Class IV cover (inverted-T-shaped slot) for 8 weeks before rain finally fell, at which time they emerged, apparently none the worse for having spent that amount of time beneath the soil (S.J. Barr, 1990, unpublished data).

Provided that rain or irrigation occurs before the subsurface seedlings have died

Table 6.2. Wheat seed and seedling responses to no-tillage openers in a dry soil and soil of adequate moisture.

	Double disc opener Vertical V-shaped slot Class I cover		Hoe opener U-shaped slot Class II cover		Winged opener Inverted-T-shaped slot Class IV cover	
	Moist	Dry	Moist	Dry	Moist	Dry
Seedling emergence	42%	10%	70%	31%	68%	59%
Germinated seeds that had failed to emerge	58%	72%	30%	22%	32%	23%
Un-germinated seeds	0%	18%	0%	47%	0%	18%
Total seed pool	100%	100%	100%	100%	100%	100%

from desiccation, it might be possible to get a positive response to watering after drilling with both vertical V- and U-shaped slots. By irrigating 22 days after a dry soil had been drilled under no-tillage, Baker (1976a) obtained an increase in emergence counts from 21% to 75% with V-shaped slots, and from 38% to 92% with U-shaped slots. With inverted-T-shaped slots, the increase was much more modest, from 78% to 86%, again because seedling emergence had already been high when the soil was in a dry state prior to irrigation.

The Effects of Pressing

One of the most common practices in tilled seedbeds is to press on the rows after covering. The practice seeks to improve seed–soil contact and attract water to the seed by capillary action. Undoubtedly it improves seed–soil contact but its function in attracting water to the seed is dubious. Cross (1959) demonstrated that, in a dry soil, consolidation under the seed was more important than consolidation above the seed, and there has always been doubt about the real benefits of pressing on tilled soils anyway.

It seems that pressing after covering in an untilled soil is of even less benefit. Choudhary (1979) and Choudhary and Baker (1981b) conducted experiments that compared pressing on the soil after covering with covering alone and pressing on the seed before covering. They found no benefit at all for pressing on the covered slots in a dry soil. Most importantly, they found substantial benefits from pressing on the seeds in the slot before covering, but only in vertical V- and U-shaped slots. With inverted-T-shaped slots, seedling emergence was already high in the absence of pressing, so there was little improvement from any subsequent pressing action.

In U-shaped slots, pressing the seed into the base of the slot ensures that the seed has good contact with the water-bearing soil. Since there is usually insufficient water vapour in U-shaped slots to germinate the seed and seed–soil contact is otherwise poor for liquid water uptake, pushing the seed

into the undisturbed soil ensures that at least liquid water uptake is available in much the same way as for V-shaped slots, as illustrated in Fig. 6.10.

In vertical V-shaped slots, pressing the seed into the base of the slot has a different effect. Embedding the seed directly into the undisturbed soil ensures that the radicle (first root) emerges directly into soil, from which it will derive its all-important water uptake (Fig. 6.11), thus bypassing the stress period when embryonic roots otherwise attempt to penetrate the slot wall. Thus, pressing on the seeds prior to covering of
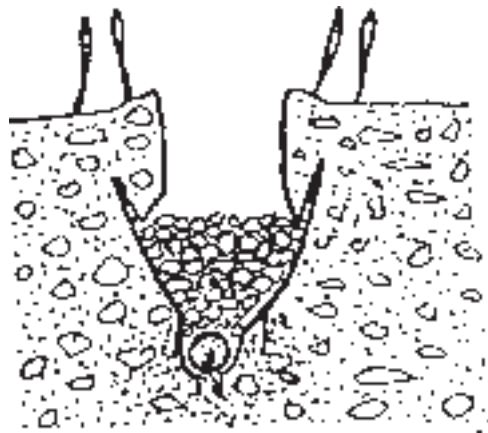
Fig. 6.10. The position of seeds after pressing in the base of a U-shaped no-tillage slot.
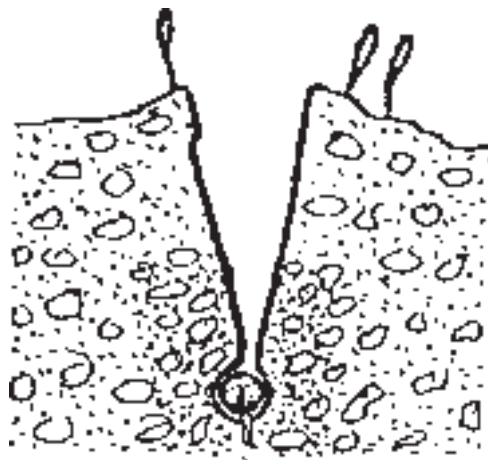

Fig. 6.11. The position of seeds after pressing in the base of a V-shaped no-tillage slot.

both U- and vertical V-shaped slots has significant benefit in terms of improving seedling emergence from a dry soil.

Field Experience

In New Zealand a field experiment sought to drill with three contrasting no-tillage opener types each second Monday for 6 summer months regardless of soil or weather conditions in order to gauge how often limiting conditions occurred in that region (Choudhary and Baker, 1982). By chance, on one occasion the soil moisture level was close to the permanent wilting point. On this occasion, inverted-T-shaped slots obtained 50% emergence of wheat, whereas U- and V-shaped slots in the same soil produced virtually no seedling emergence. It is doubtful if any seeds would have emerged from a tilled soil at or near PWP either.

It is little wonder, therefore, that repeat surveys of operators of drills with openers that created inverted-T-shaped slots in New Zealand, covering some 40,000 hectares per year in both spring and autumn sowing (Baker *et al.*, 2001), revealed a 99% success rating for the drilling process and technology.

Summary of Drilling into Dry Soils

1. The descending ranking of biological performance of slot shapes in dry soils is inverted-T-, followed by U-, then vertical V-shaped slots.

2. The descending ranking of effectiveness of slot cover in dry soils is Class IV to Class I.

3. Inverted-T-shaped slots trap water vapour within the slot, which germinates seeds as well as sustaining subsurface seedlings.

4. The predominant cause of failure of vertical V-shaped slots is subsurface desiccation of seedlings, not germination failure.

5. The predominant cause of failure of U-shaped slots is germination failure.

6. Pressing on the soil after covering the seed has negligible effect with any slot shape.

7. Pressing on the seeds in V- and U-shaped slots before covering improves their performance noticeably.

8. Surface residues are an important resource for promoting seedling emergence from dry soils, provided the openers utilize them correctly in the covering medium to trap humidity. Inverted-T- and slanted V- (but not vertical V-) shaped slots are most effective.

9. It is possible to obtain more effective seedling emergence from a dry soil using no-tillage rather than tillage, provided the correct technique and equipment are used.

10. With inverted-T-shaped slots, it is possible to obtain seedling emergence from untilled soils that are too dry to sustain effective crop growth.

7 Drilling into Wet Soils

C. John Baker

The biological ranking of no-tillage opener performance for wet soils is almost identical to that for dry soils, but for different reasons.

Unlike dry soils, it is usually impossible to physically drill into soils that are already very wet because of limitations in drill performance, limited traction or excessive compaction. Thus, in considering wet soil effects, it is important to distinguish between two different situations:

1. Drilling into soils that are sufficiently wet to make them sticky and/or plastic in nature and yet are still able to be drilled.
2. Drilling into soils that were not excessively wet at the time of drilling but that become very wet soon after drilling.

Drilling Wet Soils

The most pressing problem to drill an already wet soil without plugging (situation 1 above) from an operational point of view relates to the physical ability of openers. There are few common principles that distinguish one opener from another in this regard. In general, all openers with rotating components have limitations in wet soils, especially in wet soils that are also sticky. The use of subsurface scrapers on some disc openers will extend their tolerance of wet soils.

Where an opener employs press or gauge wheels of the semi-pneumatic ('zero-pressure') type, the operational limit of the whole opener in wet and/or sticky soils is the limit to which these tyres can continue to operate without plugging. Semi-pneumatic tyres are particularly good at shedding mud (see Chapter 10), so it is illogical to expect an opener to handle wet soils any better than its tyres.

Putting to one side the ability of different openers to operate without plugging, there are important biological effects that also arise as a result of the physical action of different openers in wet soils. The most important biological factor is the amount of compaction, smearing and crusting created by different openers. Smearing is very localized compaction within the slot (perhaps only 1–2 mm thick) and crusting is usually a smear that has dried hard.

Dixon (1972) illustrated the effects of vertical double disc openers (V-shaped slot), simple hoe openers (U-shaped slot) and simple winged openers (inverted-T-shaped slot) at different soil moisture contents, one of which was quite wet (27%) (Fig. 4.1). Several others have also studied the tendencies of different openers to compact the base and side walls of the slot

(Dixon, 1972; Baker and Mai, 1982b; Mitchell, 1983). From these studies and countless field observations, the compaction, smearing and crusting tendencies of different openers can be summarized as follows.

Vertical double (or triple) disc openers (V-shaped slots)

These have the strongest compaction tendencies of all no-tillage openers. Compaction occurs at both the base and side walls of the slot. They also have a strong smearing tendency, which is accentuated by the open slot. Because the smears are open to the elements, they often dry after passage of the opener and soon become internal crusts, which restrict root penetration.

In sticky wet soils, soil clings to the outside of the discs, which lift soil and seed from within the slots and deposit them alongside, thus negating the true V shape of the slots. Figure 4.5 shows a slot made by a vertical double disc opener in a sticky Australian soil. The slot has been severely disrupted by soil sticking to the disc.

Vertical double or triple disc openers have a strong tendency to tuck (or hairpin) residue into the slot, as described in more detail later. The slot cover is typically Class I.

Slanted double (or triple) disc openers (slanted V-shaped slots)

These are somewhat less likely to compact the seed zone but only if the seeding opener is preceded by another double or triple disc fertilizer opener slanted in the opposite direction. Because of the slant, the upper side of the slot wall created by the first opener actually heaves the soil upwards and loosens it somewhat. Although the second slanted opener actually compacts the soil beneath it more than if it had been operating in a vertical position, the pre-loosening of this soil by the first opener, which normally operates somewhat deeper than the second opener, negates most of the harmful effects.

Where a slanted double or triple disc opener is not preceded by a similar opener slanted in the opposite direction, the compaction beneath the opener will be greater than if the opener had been operating vertically. Compaction above the opener will be relieved, but loosening will have little effect on root penetration of seedlings, although it will improve the moisture-retention properties of the slot, which in turn will reduce the risk of the internal surfaces of the slot drying to form crusts.

Slanted double or triple disc openers otherwise have all of the same problems associated with their vertical counterparts, including hairpinning of residue into the slot zone and a tendency for sticky soils to cling to the outside of the disc and disrupt the integrity of the slot shape. The slot cover varies from Class II to Class IV.

Vertical angled flat (or dished) disc openers (U-shaped slots)

These have little or no compaction tendencies and little or no tendency to smear or lift soil in sticky conditions. Covering of the slots may be difficult, however, in continued wet weather, for the same reasons later outlined for hoe-type openers. Angled disc openers also tend to tuck (or hairpin) residue into the slot (see below). The slot cover is typically Class I or II.

Hoe-type openers (U-shaped slots)

These usually result in little compaction, unless they are of a design that has a large flat base, in which case they may compact the base of the slot, but not the side walls. In wet soils they almost invariably create smears on the base and side walls of the slot. These become important if the slot remains uncovered after drilling and the smears are allowed to dry to form crusts.

Covering is a particular problem. Hoe openers rely on the covering device collecting up the spilled soil alongside the slot and brushing it back over the slot as covering material. In a wet soil, such covering material

is unlikely to become crumbly, so the slot is difficult to cover at all, encouraging eventual crust formation.

If covering needs to be a separate operation, its effectiveness depends on allowing sufficient drying for crumb to form in the debris alongside the slot, but not so much drying as to allow any smears within the slot to become crusts. Thus, although hoe openers can be used successfully in wet soils, they require a high level of skill to overcome their shortcomings. Hoe openers can experience problems in sticky soils if soil accumulates on the sides of the opener and changes its shape and dimensions. The slot cover is typically Class I.

Power till openers (U-shaped slots)

These mostly compact the base of the slot and may smear that zone as well. This smearing and compaction, however, are seldom severe and, because the soil is not often spilled completely out of the slot, the smears are usually not at risk of becoming crusts unless a very severe drying period follows drilling.

Power till openers mechanically aerate the soil more than any other opener type, which can be beneficial in wet soils with low residue levels and only small populations of earthworms. On the other hand, some power till openers may become totally inoperable in sticky wet soils due to 'plugging' between the cutting blades. The slot cover is typically Class IIIb.

Winged openers (inverted-T-shaped slots)

These smear the base of the slot about as much as most hoe openers but result in minimal compaction. Like power till openers, winged openers have an advantage in that they either close the slot themselves or make closure by a separate device easy and not dependent on moisture or weather. Thus, smears do not become crusts and therefore do not restrict root growth.

Winged openers handle sticky soils reasonably well. The disc version of the opener uses subsurface scrapers to overcome the tendency of sticky soils to cling to the disc. Figure 7.1 shows the benefits of scrapers used on a winged opener in the same sticky Australian soil as depicted in Fig. 4.5. The integrity of the slot and the residue cover have remained intact. The slot cover is typically Class IV.

Figures 7.2 and 7.3 show sections of soil in the side walls of two no-tillage slots photographed with an electron microscope (Mai, 1978). The lighter grey areas in the uncompacted soil in Fig. 7.2 are natural voids and macropores. In addition, much organic matter in the form of roots and buried residue is visible. In contrast, the compacted soil in Fig. 7.3 has almost no macropores and little visible organic matter. Instead, it contains only a few cracks in which soil oxygen can circulate. It is obvious why earthworms prefer soil surrounding inverted-T-shaped slots to that which surrounds V-shaped slots.

Soil type is also important in wet-soil seeding. If a small handful of soil can be 'ribboned' by rubbing it between the thumb and forefinger, it will probably become smeared by those openers that have smearing tendencies. In general, sandy soils and well-structured loamy soils with reasonably high levels of organic matter seldom take on smears or become permanently compacted by passage of no-tillage openers. Many clay soils take on a smear readily when wet. Montmorillonitic clays may become sticky instead. Silty soils lie in between clays and sands.

Many of the sticky montmorillonite clays produce good crops because of their incredible water-holding capacity. They also have a strong tendency to shrink when drying. This produces internal cracking, forming quite deep fissures in the soil. During the early stages of drying and cracking, the soil mass breaks itself into smaller particles by shrinkage, almost as if it had been tilled. Such soils are said to be self-mulching. They produce a dilemma for tillage practices. Because they are so sticky when wet, they are difficult to work in that

Fig. 7.1. Class IV slot cover remaining intact after passage of a winged opener, equipped with scrapers (inverted-T-shaped slot), through a damp sticky soil (compare with Fig. 4.5).
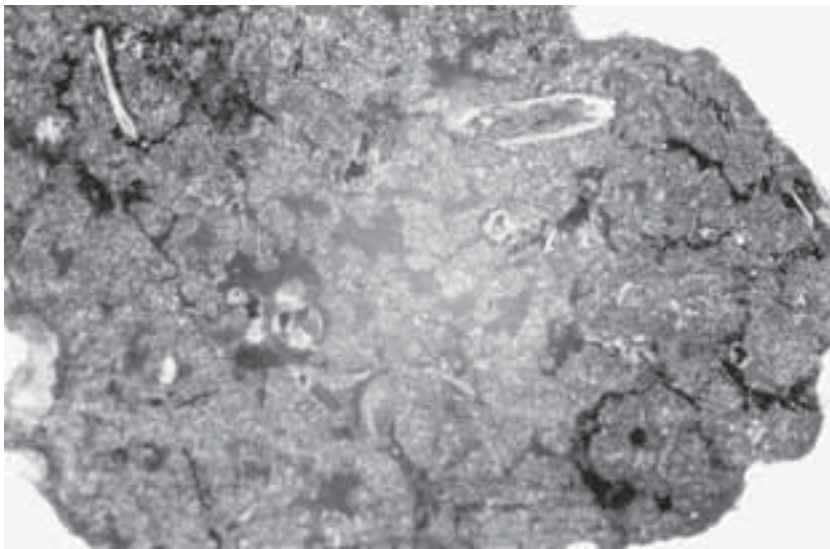
Fig. 7.2. Electron-microscopic section of soil from the wall of an inverted-T-shaped slot (from Baker and Mai, 1982b).

state with tillage equipment. But waiting until they dry and are easier to work risks sacrificing valuable soil water during the drying and tillage periods.

No-tillage offers a realistic option for such soils, since it allows sowing directly into the untilled soil with minimal disturbance. This is best done when only a small
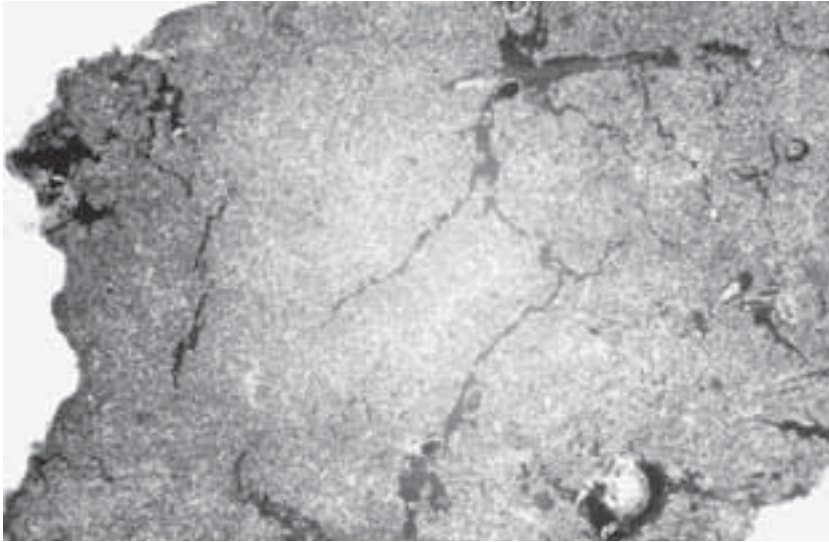
Fig. 7.3. Electron-microscopic section of soil from the wall of a V-shaped slot
(from Baker and Mai, 1982b).

amount of surface drying has occurred. Avoiding inversion of the deeper, more moist layers during drilling then becomes an important function of the no-tillage openers, both because such inversion brings up wet soil that sticks to everything and because it results in unnecessary loss of soil moisture. This contrasts with continuous tillage, in which the resistance of soils to compaction and smearing declines with time and continuous working. Vehicle traffic exacerbates the situation, leading to a cumulative decline in the usefulness of such soils when they are worked in a wet state. Since the practice of no-tillage gradually increases SOM levels and structure over time, many soils are likely to become less liable to smear or compact with time and therefore better able to be drilled when wet.

Drilled Dry Soils that Become Wet

Drilling dry or moist soils that have yet to become wet will not create substantive smearing or compaction problems with any design of opener. Thus, the differences between openers reflect the abilities of the various slot shapes to create micro-environments that will remain beneficial to seeds, seedlings and growing plants even after the soils have subsequently become wet. The most important criterion is their effect on the oxygen status of the soil, since roots breathe, and saturation by water will otherwise drown both seedlings and beneficial soil fauna.

Wet soils, especially when they have not been tilled, have a complex relationship with seeds. For example, if the soil has not been tilled for some time and has a reasonable population of earthworms, the earthworms will have an important effect on oxygen diffusion in the seed zone and water drainage. Their burrowing activity provides channels for air entry and water exit.

Earthworms also need feeding. They respond rapidly to the presence or absence of food supplies. There are several species of earthworm and each species prefers to occupy a certain depth range of soil. Those that feed on surface residues (e.g. *Lumbricus rubellus* Hoff and *Allolobophora caliginosa* Sav) live near the surface and are the first to react to excess water on the soil surface. They also react to the presence or absence of residues, which comprise their food supply, even to the extent that their

burrowing and casting will reflect the presence of surface residues only a few centimetres apart.

In experiments with no-tillage openers in soils that were to become wet, Chaudhry (1985) tested the effects of the presence or absence of surface residues. 'Residue' plots had long, rank ryegrass (*Lolium perenne*) growing on them, which was sprayed. 'Non-residue' plots had this grass removed at ground level just before drilling. Within 24 h of mowing, the earthworm populations in the 'non-residue' plots had halved, presumably as a response to the removal of their principal food source.

It has also been observed that earthworms appear to have a preference for the disturbed slot zone in a soil after drilling, as opposed to the undisturbed soil alongside, but only if this slot zone is covered with a ready source of food (residue) and only if it is not compacted. Presumably they find the loosened soil easier to burrow through and the covering of residue provides an improved environment and a convenient food source.

Table 7.1 shows the effects on seedling emergence of barley (*Hordeum vulgare*) in a wet soil by the three common slot shapes with and without surface residues (Chaudhry, 1985; Chaudhry and Baker, 1988). The table also shows the numbers of earthworms recovered from 120 mm diameter × 100 mm long soil cores centred on the drilled rows. The index of earthworm activity, measured as the percentage of the area of ground covered by earthworm casts, showed similar trends to the numbers of earthworms counted in the soil cores. To create very wet conditions after drilling in this experiment, the soil was irrigated with 20 mm of simulated rainfall per day over a 4 h period, for 20 days (total, 400 mm in 20 days). In a field situation, such an intensity of repeat rainfall would be expected to produce supersaturated conditions and surface puddling in a short time span. In the free-draining bins used in this experiment, supersaturation did not occur but the soil none the less remained above 'field capacity' most of the time.

There were three strong trends in the data of Table 7.1. First, the greatest seedling emergence was promoted by the surface broadcast treatment (87%) and inverted-T-shaped slots created by winged openers (76%) (no statistical difference). Next were U-shaped slots created by hoe (65%) and power till (63%) openers. The vertical V-shaped slots created by double disc openers and the U-shaped holes created by a simulated punch planter performed poorly (24% and 17% seedling emergence, respectively).

Secondly, the number of earthworms found in cores of soil centring on the drilled rows mirrored very closely the seedling emergence counts. Most earthworms were found in the vicinity of the slots created by the winged (25), hoe (22) and power till (23) openers, together with surface broadcasting (22) and perhaps the punch planter (18), but the vertical double disc opener (9) performed poorly.

Thirdly, the presence or absence of residues had a very positive effect on both seedling emergence and earthworm numbers with the inverted-T- and some of the U-shaped slots and holes, but not with V-shaped slots or with surface broadcasting. Residues improved seedling emergence with the inverted-T-shaped slots from 48% to 76% and earthworm numbers from 13 to 25. The effect on U-shaped slots was not quite so marked, but residues none the less improved seedling emergence from 40% to 65% and earthworm numbers from 13 to 22 with the hoe opener.

In contrast, residues actually depressed seedling emergence with the vertical double disc openers (from 25% to 17%) and punch planter (from 17% to 14%), but had no effect with surface broadcasting or power till openers. The latter phenomenon is not surprising since the power till opener chopped up the surface residues (and probably a number of earthworms) and incorporated them into the soil. With surface broadcasting, the seeds were left lying on top of the ground, making them less likely to be affected by earthworm activity taking place beneath the surface. Further, because moisture was not limiting, it is not surprising that residues on the soil surface had no direct effect on emergence with broadcasting.

Table 7.1. Effects of no-tillage openers on barley seedling emergence and earthworm numbers in a wet soil after drilling.

	Double disc opener vertical V-shaped slot Class I cover		Hoe opener U-shaped slot Class I cover		Winged opener Inverted-T-shaped slot Class IV cover		Power till opener U-shaped slot Class IIIb cover		Punch planter opener U-shaped holes Class I cover		Surface broadcast No slot Class I cover	
	R	NR	R	NR	R	NR	R	NR	R	NR	R	NR
% seedling emergence with earthworms	17	25	65	40	76	48	63	62	17	15	84	87
Earthworm number (per core)	9	8	22	13	25	13	23	14	18	10	22	14
% seedling emergence without earthworms	15	19	24	23	20	22	43	41	14	16	89	89

R, plots covered with surface residues, both before and after drilling; NR, plots with no surface residue covering, either before or after drilling.

These results suggest that all three observed trends are linked in a wet soil. Indeed they are. The third line of Table 7.1 illustrates emergence when earthworms were eliminated from the soil by poisoning in an otherwise identical experiment.

Without earthworms, seedling emergence was weakened with all drilling treatments. Most residue advantages with inverted-T- and U-shaped slots disappeared in the absence of earthworms, indicating a strong linkage between the three factors when they were present. This also demonstrates one of the longer-term benefits of no-tillage, that of building up earthworm numbers and organic matter, which work to the advantage of this farming system, provided that appropriate equipment is used to maintain and capitalize on those benefits.

The data of Table 7.1 also illustrates that mechanical aeration can to some extent substitute for the absence of natural aeration caused by earthworms and other soil fauna. The chemical treatment to kill earthworms also kills some of the other channel-forming soil fauna. Although the use of power till openers may only be of short-term benefit when drilling into soils that subsequently become wet, this was the only opener to promote more than 24% seedling emergence in the 'sterilized' soil.

Even then, the 43% emergence obtained with this opener in residue and the 41% without residue cannot be regarded as satisfactory and do not compare with the 76% obtained with the winged opener in the presence of both earthworms and residues.

Surface broadcasting promoted the highest seedling emergence counts in the absence of earthworms (89% both with and without residue), presumably because seeds on the surface were unaffected by earthworm activity beneath it. But this treatment can hardly be considered a recommended field practice unless one can guarantee 400 mm of rainfall for the first 20 days after sowing. It was used in this experiment solely to compare the seed's need for oxygen and water.

Figure 7.4 illustrates similar responses to those just presented for inverted-T-shaped slots, hoe (U-shaped slots) and vertical double disc (V-shaped slots) openers. The most noticeable effects are that the seedling emergence trends follow the trends of earthworm numbers with all openers and that residues increased both emergence and earthworm numbers with the inverted-T and hoe openers but not with vertical double disc openers.

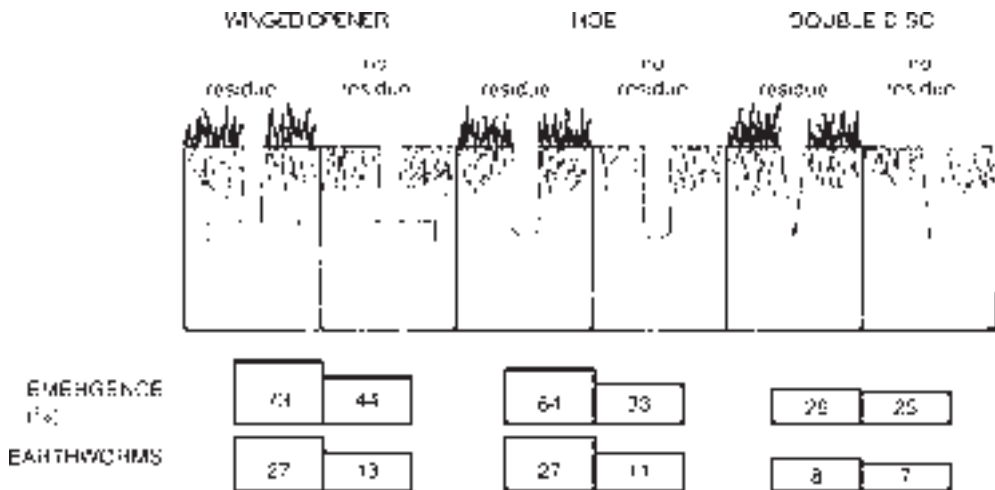To further understand the interactions between opener types, the moisture status

Fig. 7.4. Responses of seedling emergence and earthworm numbers to three contrasting, no-tillage slot shapes and surface residues in a wet soil (from Baker *et al.*, 1996).

of the soil and the level of residues present, Chaudhry (1985) conducted an experiment in which these factors were varied independently. The results are shown in Table 7.2.

The data show that most openers performed reasonably well in favourable soil moisture conditions, regardless of the level of residue (range, 65–90% seedling emergence). When the conditions became wet, however, the shortcomings of the vertical double disc opener (V-shaped slot) became progressively more apparent as the length of the residue increased. In the wet soil, emergence from the V-shaped slot dropped from 38% with no residue to 35% with short residue and 30% with long residue. The winged and hoe openers, in contrast, performed best when long residue covered the wet soil, which was attributable to the increase in earthworm activity in response to the long residue. As the residue length was reduced with these two openers, their advantages over the vertical double disc opener were reduced or eliminated.

Although the hoe opener responded positively to long residue, it is difficult to actually make a hoe-type opener function in long residue in the field. It is one thing to do this on a plot scale for experiments but, in the field, hoe openers soon block because of their raking action. In practical terms, therefore, of the two openers that performed well in wet soils with long residue, only the winged opener (inverted-T-shaped slot), which is able to handle residues in its disc form, can be regarded as a practical option.

Opener performance

The performance of various seeding openers in soil (that is, wetted after seeding) can be summarized as follows.

Power till openers (U-shaped slots)

These openers, in the absence of earthworms, will provide some compensatory mechanical aeration. The presence of earthworms, however, will not necessarily result in any improvement to seedling emergence because the gains that mechanical aeration brings to an earthworm-populated soil are offset by physical burial of the food source for any surface-feeding earthworms. There will also be some actual destruction of earthworms in the slot zone, but because the width of tillage by such openers is normally very narrow, it is likely that the slot zone will be rapidly recolonized by earthworms from the undisturbed soil alongside.

Punch planting (V- or U-shaped holes)

This is not likely to produce good results, with or without earthworms, although further work needs to be conducted with such openers. The poor performance of the punch planter in these experiments was somewhat surprising since the method used to make holes did not result in any compaction. In practice, punch planters almost invariably produce V-shaped holes, which could be expected to behave in much the

Table 7.2. Effects of openers, residue levels and soil moisture status on barley seedling emergence from a soil containing earthworms.

	Seedling emergence %								
	Vertical double disc opener V-shaped slot Class I cover			Hoe opener U-shaped slot Class I and IIIa cover			Winged opener Inverted-T-shaped slot Class IV cover		
	LR	SR	NR	LR	SR	NR	LR	SR	NR
Adequate moisture	65	84	82	86	70	76	90	76	82
Wet soil	30	35	38	68	36	42	75	43	47

LR, long residue; SR, short residue; NR, no residue.

same way as continuous V-shaped slots. In this case, however, a small coring device was used to remove cores of soil without compaction.

Vertical double disc openers (V-shaped slots)

These can be expected to perform poorly in wet soils for two reasons. First, compaction and smearing, together with crust formation, result in earthworms avoiding the slot area. Thus, not only does the opener disadvantage the seeds directly, it discourages natural processes (earthworms) from repairing the damage.

To examine the tolerance of earthworms to smearing, Chaudhry (1985) placed a number of earthworms on the surface of a damp, smooth soil contained in two high-sided pots (to prevent escape of the earthworms). Before placing the earthworms on the soil, he lightly smeared the surface of one of the plots with his finger. Overnight, all of the earthworms on the un-smeared soil had burrowed into the soil while only half had achieved the same result in the smeared soil, indicating the difficulty earthworms have in burrowing through smears.

Chaudhry (1985) also tested the tolerance of earthworms to compaction and found much the same result as for smears. Because wet soils are softer than dry soils, the action of vertical double disc openers acting through surface residues on wet soils is more one of pressing than cutting. This accentuates their compaction tendency. Slots that are both smeared and compacted are largely avoided by earthworms and do not benefit from their burrowing or nutrient cycling (Baker *et al.*, 1987, 1988).

Secondly, double disc openers tuck (or hairpin) residues into the slot. In wet soils, Lynch (1977, 1978) and Lynch *et al.* (1980) showed that the decomposition of this residue produces fatty acids, in particular acetic acid, which tend to kill seeds and germinating seedlings. They looked at ways of countering this problem, ranging from applying lime with the seed to neutralize the acid to separating the seed from the residue.

Apparently, separation of the two by only a small distance will largely avoid the problem since acetic acid is very quickly broken down in the soil by bacteria. The residue tucking problem is reflected in the negative response to the presence of residue by the vertical double disc opener and the fact that this negative response increased as the length of residue (and size of hairpins) increased.

Although slanted double disc and angled disc openers were not included in the above experiment, it is known that both of these openers also tuck residue into the seed zone, in much the same manner as vertical double disc openers. They can therefore be expected to experience acetic acid fermentation and its detrimental effects on seeds, but should experience fewer problems associated with smearing or compaction.

Winged openers (inverted-T-shaped slots)

These return most of the residue to a position over (not inside) the slot. This encourages earthworms to colonize the slot zone because when the residue is removed, the earthworm numbers decline noticeably. The central disc of the disc version of the winged opener will hairpin residues, in common with every other disc-type opener. But the winged side blades of this opener place the seed to one side of the central slit and therefore remove the seed from contact with the hairpinned residue. This is probably the only disc-type opener that effectively prevents seeds from lodging within hairpins and for this reason benefits from the presence of residues even in wet conditions. When long residue was positioned over the slot, the inverted-T slot produced more seedling emergence than any other design.

Hoe openers (U-shaped slots)

These behave in a similar manner to winged openers except that instead of placing the residue over the slot, they tend to push it to either side. As a consequence, although hoe openers will produce a positive response to the presence of residue (in terms of seedling

emergence and earthworm numbers), that response is not likely to be as strong or as positive as for winged openers.

The seedling emergence responses of the various openers and surface broadcasting have also been reflected in root and shoot weights of the seedlings, as shown in Figs 7.5 and 7.6 (with and without earthworms, respectively).

Without earthworms, there were few differences between openers. Only the mechanical aeration of power till openers had any positive effect. With earthworms, however, the seedling growth closely paralleled the trends of seedling emergence and earthworm numbers.

Figure 7.7 shows typical oxygen diffusion rates within the soil containing earthworms associated with winged and double disc openers (Chaudhry, 1985; Baker *et al.*, 1987, 1988). Oxygen diffusion rate is measured by passing a current through platinum electrodes placed in a grid pattern around the sown slots and measuring the rate of consumption and replacement of oxygen in the vicinity of the electrodes (see Chapter 19).

Figure 7.7 shows that the winged opener had no negative effect on the oxygen status of the soil. The oxygen status surrounding the hoe, power till and punch planter openers (not shown) was very similar to that of the winged opener. In fact, all of these openers had similar patterns to that of the undisturbed soil, indicating that none of them had any detrimental effect on the oxygen diffusion rate of the soil. But, in all cases, the presence of residues moved the high-oxygen zones closer to the seeds, probably as a result of increased earthworm activity.

In contrast, the double disc opener had a marked negative effect on the oxygen status of the soil, regardless of the presence or absence of residues. Essentially, this opener, because of its wedging action, squeezes the high-oxygen zones away from the immediate vicinity of the seeds altogether and replaces them with compacted zones of low or, at best, medium oxygen diffusion.

Also of note is that the effects of wetness on the soil, both with and without earthworms, seems not to be related to how the soil becomes wet. For example,
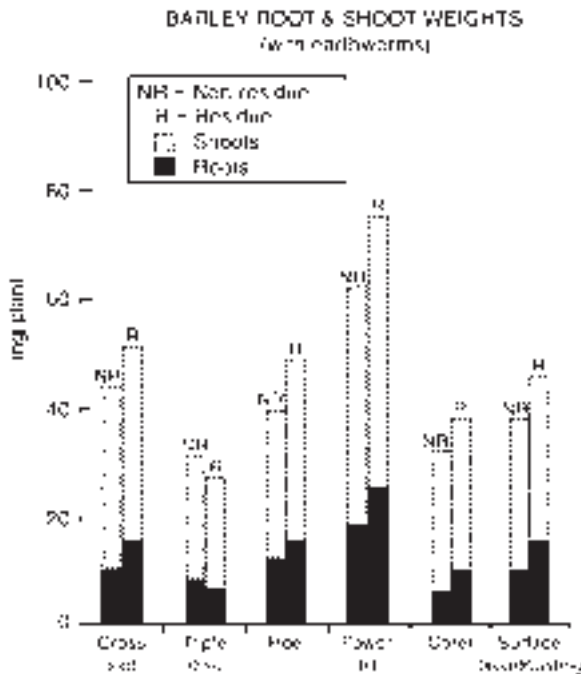
Fig. 7.5. Root and shoot weights of no-tilled barley seedlings in response to opener types and residue in the presence of earthworms (from Baker *et al.*, 1988).

BARLEY ROOT & SHOOT WEIGHTS
(without earthworms)
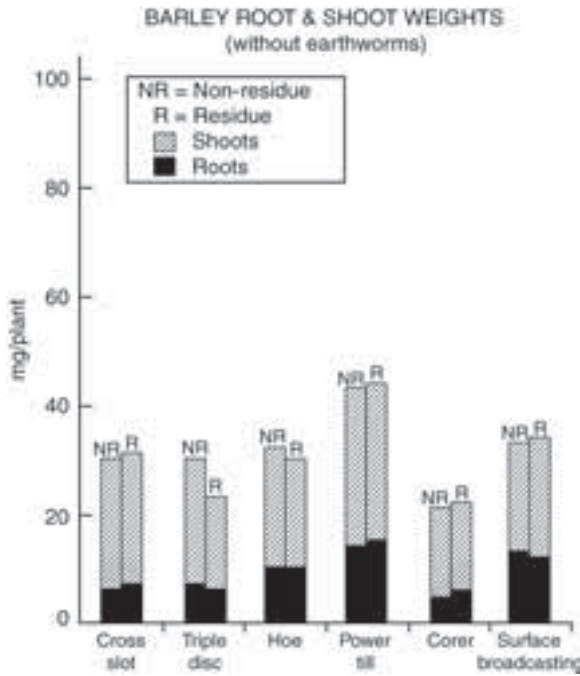
Fig. 7.6. Root and shoot weights of no-tilled barley seedlings in response to opener types and residue in the absence of earthworms (from Baker *et al.*, 1988).
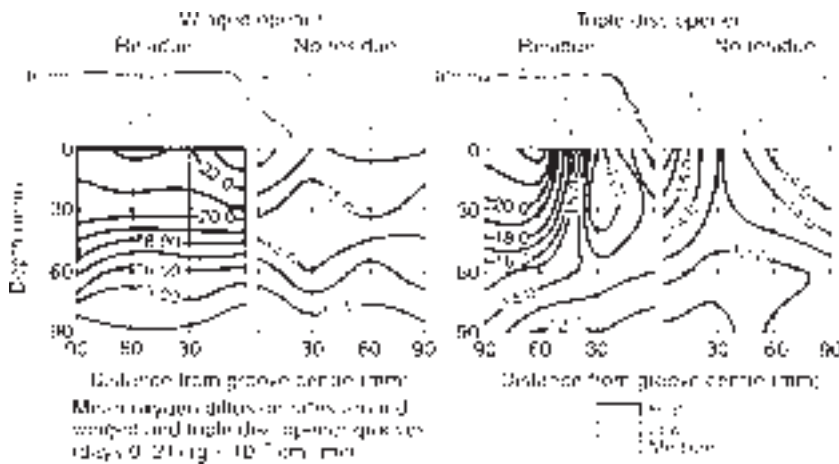
Fig. 7.7. Oxygen diffusion rate profiles around winged and double disc no-tillage openers operating in a wet silt-loam soil, in the presence and absence of surface residues (from Baker *et al.*,1988).

Chaudry (1985) had earlier conducted two experiments with earthworms and residue, identical in all respects except that one used simulated rainfall to wet the soil after drilling and the other used a rising water table. He was particularly interested in whether or not persistent rainfall had some sealing effect on the internal faces or the cover, or, alternatively, washed the seed out. He found no differences in barley seedling performance between wetting the soil from above or below, but both experiments confirmed the differences between openers and residue.

Later, Giles (1994) quantified the rate of accumulation of earthworm biomass in the top 100 mm of soil as a function of different levels of barley straw on the surface of the ground in New Zealand. He found an almost linear relationship, in which the total biomass of two surface-feeding species (*L. rubellus* Hoff and *A. caliginosa* Sav) had accumulated to 9 t/ha under 11 t/ha of straw and 5.1 t of earthworms under 6.4 t/ha of straw. During that period the recoverable biomass of the straw had decreased from 11 t/ha to 3.2 t/ha and 6.4 t/ha to 1.2 t/ha, respectively. For the first 6 months, the heavier rate of residue remained wetter than the lighter rate, which might help account for the faster decomposition of the former. At the termination of the experiment, a part

of the residues appeared to have decomposed while another part had simply been buried by earthworm casts.

It should be appreciated that these levels of cereal straw were deliberately set very high to test the ability of earthworms to cope with 'overload' conditions under no-tillage. In general terms, such straw levels equate with grain yields of about the same magnitude.

Finally, experiments relating to wet soils would not be complete without also measuring the infiltration of water into the slot zones in the field. Figure 7.8 shows the results of a field experiment that compared the infiltration rates of a range of openers in a residue-covered silt-loam soil containing earthworms (Baker *et al.*, 1987). The results
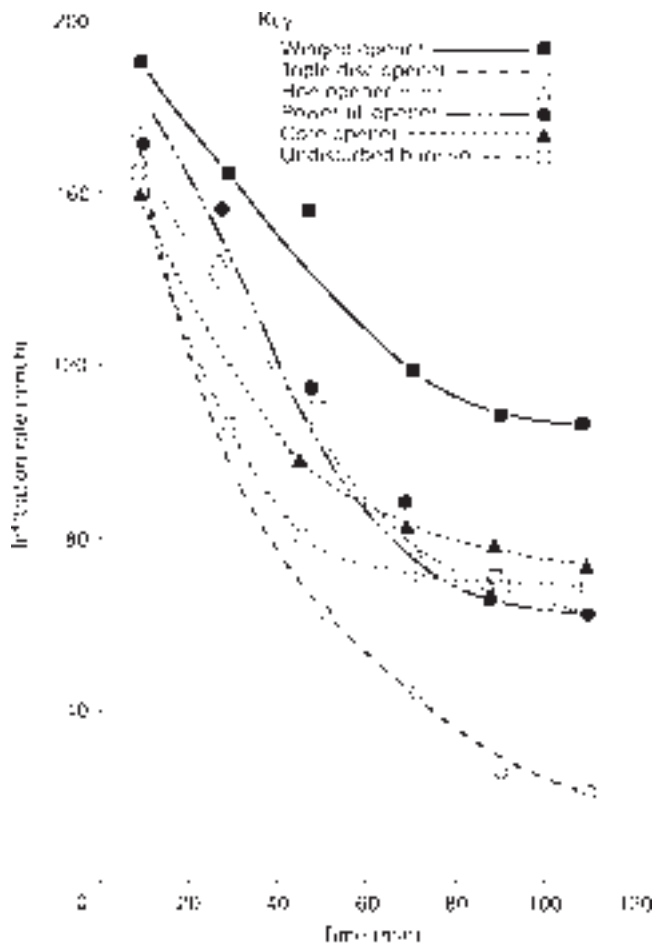
Fig. 7.8. Infiltration rates of no-tillage slots in a silt-loam soil (from Baker *et al.*, 1987).

reflect earthworm and seedling emergence trends. The winged opener (inverted-T-shaped slot) produced the most rapid infiltration (110 mm/h after 2 h), which is not surprising since it had promoted the greatest earthworm activity and seedling emergence. Next was a group of openers including hoe, power till (U-shaped slots) and punch planter (U-shaped holes), together with the undisturbed soil, all of which averaged 70 mm/h after 2 h. The poorest infiltration was with the double disc opener (V-shaped slots), with only 20 mm/h infiltration after 2 h. Water remained puddled in the V-shaped slots for hours after the experiment.

Summary of Drilling into Wet Soils

1. The ranking for the three basic slot shapes from poorest to best (V, U and inverted-T) in wet soils containing earthworms and residues is exactly the same as for dry soils, but for somewhat different reasons.
2. Seeds need ready access to oxygen in a wet soil, and different openers create different oxygen environments around the seeds in wet soils.
3. Double disc openers have an adverse effect on the oxygen diffusion rate of the soil surrounding the seed slot.
4. Inverted-T, hoe and power till openers, together with punch planters, have either a neutral or positive effect on oxygen diffusion around the slot.
5. Both earthworms and surface residues give clear-cut advantages if managed correctly. Both will increase with time under no-tillage and have an increasingly positive effect on aeration, drainage and infiltration.
6. Winged and hoe openers encourage earthworm activity in the slot zone.
7. Surface residues encourage earthworm activity, with the amount of activity being proportional to the amount of residue.
8. The ability of the inverted-T-shaped slot (winged opener) to retain residue over the slot is as important in wet soils as it is in

dry soils because it encourages earthworm activity within and around the sown slot.
9. Double, triple and angled disc openers, together with punch planters, tend to tuck (hairpin) residue into the seed zone, where it has a negative effect on germination and seedling vigour. This is especially true of long, stringy and damp residue.
10. Winged, hoe, power till and furrow openers effectively separate decaying residue from direct contact with seeds.
11. In the absence of earthworms, mechanical aeration of the slot by power till openers may have a short-term benefit.
12. Surface broadcasting can perform well if regular daily rainfall is available for 3 weeks after sowing, but obviously this cannot be regarded as a practical option.
13. V-shaped slots and punch planter holes tend to be compacted and/or smeared. Class I cover (or lack of cover) allows these smears to dry to form crusts.
14. Smears and/or crusts discourage earthworm activity in the slot zone.
15. U-shaped slots created by hoe, power till and furrow openers may be smeared but only minimally compacted. If Class II cover or better is possible, the smears should not dry to become crusts.
16. U-shaped slots created by angled disc openers will not be smeared or compacted.
17. Inverted-T-shaped slots created by winged openers may be smeared but not compacted. Class IV cover will prevent drying of smears.
18. Excellent water infiltration is possible with inverted-T-shaped slots but infiltration is likely to be poor with V-shaped slots created by double or triple disc openers. But infiltration between the rows can be expected to be greater with no-tillage than with traditional tillage anyway, particularly with increased earthworm populations and organic matter.
19. Excellent seedling emergence can be obtained by inverted-T-shaped slots in wet soils, and satisfactory emergence can be obtained by most of the openers that create U-shaped slots.
20. Poor seedling emergence will result from V-shaped slots or holes in wet soils.

8 Seed Depth, Placement and Metering

C. John Baker and Keith E. Saxton

Accurate seed placement is more important in no-tillage than in tillage.

When an opener on a no-tillage drill or planter deposits seed, and perhaps fertilizer, into the soil, its ability to control the final placement and environment of each depends on a number of sometimes contradictory functions. The required combined capability of the drill or planter and soil opener includes:

1. Continuously following the soil surface of each row and maintaining precise seeding depth.
2. Dispensing seed under the soil, on the move, in a consistent band relative to the opener itself.
3. Covering the seed (and perhaps fertilizer) or at least making provision for effective covering after the opener has passed.
4. Separating the seed from the fertilizer if the two are being placed at the same time and optimizing the positions of each relative to one another so as to maximize biological responses.
5. Metering and dispensing seed at the desired spacing and in the desired pattern along the row.
6. Transferring seed from the metering mechanisms to the openers without disrupting the intended spacing or pattern.

Functions 1–3 are important for proper seed placement and function. Function 4 is important for fertilizer placement, as described in Chapter 9. Functions 5 and 6 (and, to some extent, 1) are dependent on the design of the whole drill or planter, especially the drag-arm configuration and downforce mechanism, as well as the openers.

Placing seed and fertilizer in the soil is a function of opener design. For optimum performance, openers need to have the ability to:

- Ignore or control soil disturbance beneath the ground surface (or lack of it when soils are wet).
- Ignore soil stickiness.
- Cope with stones and other obstructions beneath the surface.
- Avoid depositing seeds in hairpinned residue.
- Prevent seed bounce.
- Cover the slot to a consistent depth.

Covering might be a separate operation performed by a separate machine (e.g. harrows), in which case the openers should create the slots in such a way that the covering operation will result in a consistent depth of cover (see Chapter 5).

Seed metering is a function of the seed metering mechanism of the drill or planter

and is not peculiar to no-tillage. In general, a precision planter is distinguished from a drill by the fact that a planter dispenses single seeds with the intention that the seeds are placed a predetermined distance apart. A drill, on the other hand, dispenses seeds in bulk so that a given number (or weight) of seeds is deposited in a given length of row (or area) in an approximately uniform distribution with no attempt at individual seed spacing.

Transferring seed from the metering mechanism to the opener might seem a mundane function, but, with precision metering especially, this transfer must maintain the continuity of metered seed timing for accurate spacing in the row. Agronomists argue about the effects of variations in seed spacing on crop yield, especially when this is traded off against the natural variation between plants and their abilities to compensate for imperfect spacing. But most experts agree that there is little agronomic disadvantage from having seeds spaced at precise intervals along the row. Recent evidence for maize suggests that uniform seeding depth and emergence are likely to be more important than plant spacing.

Seeding Depth and Seedling Emergence

Almost everyone agrees that seeding depth should be as consistent as possible. But surprisingly there have been few studies quantifying the target depths for seeds sown under no-tillage (as distinct from tillage) or the crop performance effects of variations around that target depth. Obviously, the importance of this factor will vary with the compensatory growth potential of any given crop or species.

To quantify the effects on seedling emergence of imperfect drilling depth under no-tillage, Hadfield (1993) measured the variations in germination and emergence of wheat (*Triticum aestivum*) and lupin (*Lupinus angustifolius*) drilled in inverted-T-shaped no-tillage slots at various depths. The results are shown in Table 8.1.

Hadfield concluded that the particular variety of wheat he used (cv. Otane) was less sensitive to depth of sowing than lupin in the 20 mm to 50 mm depth range, but both were seriously affected by depths greater than 50 mm. Overall, seedling emergence with this variety of wheat decreased by 4% for each 10 mm increase in drilling depth between 20 mm and 70 mm. But other varieties of wheat have been observed to have quite different tolerances of depth. In comparison, in these experiments lupin emergence declined by 17% for each 10 mm increase in depth between 20 mm and 70 mm. In both cases, the reduction in seedling emergence was not caused by failure of seeds to germinate but by subsurface mortality of seedlings that had already germinated. This confirmed earlier observations by Heywood (1977).

Campbell (1981, 1985) also studied drilling depths of a small-seeded pasture legume, red clover (*Trifolium pratense*), sown in inverted T-shaped no-tillage slots. He concluded that seedling emergence of

Table 8.1. Effects of drilling depth on seedling emergence of no-tilled wheat and lupin.

Nominal drilling depth	Seedling emergence* (plants per square metre in parenthesis)	
	Wheat	Lupin
20 mm	79% (209) a	93% (66) a
30 mm	80% (210) a	87% (62) b
50 mm	73% (192) a	60% (43) c
70 mm	61% (160) b	24% (17) d

Unlike letters in a column denote significant differences, $P < 0.05$.
*% seedling emergence = % of the estimated number of seeds sown from the known weights of seeds sown.

Table 8.2. Effects of drilling depth on seedling emergence of no-tilled red clover.

Nominal drilling depth	Seedling emergence* (%)
0 mm	53% b
13 mm	89% a
38 mm	56% b

Unlike letters in the column denote significant differences, $P < 0.05$.
*% seedling emergence = % of the estimated number of seeds sown from the known weights of seeds sown.

pasture legumes was particularly sensitive to drilling depths above and below his mid-treatment, 13 mm. The results are shown in Table 8.2.

Salmon (2005) examined the effects of seeding depths (from 0 to 50 mm) on the emergence of brassica seedlings when sown into a range of no-tillage soils in New Zealand using the disc version of winged no-tillage openers. He also sought interactions with seed treatments, which ranged from coated (Superstrike), insecticide-treated (Gaucho®), to bare (untreated) seed.

He concluded that, with this particular opener, which is known to create a favourable environment for both seeds and seedlings, depths of sowing from 10 to 25 mm had no significant effect on the rates or final counts of seedling emergence, but that zero depth and 50 mm depth reduced emergence markedly. There were no interactions between seeding depths and seed treatment.

Salmon was not able to test the effects of low seed vigour, other brassica species and/or other no-tillage opener types in these experiments. It is doubtful, however, if any of these factors would have improved the range of sowing depths found possible, which was considered to already be unusually broad in Salmon's experiments.

Maintaining Consistent Opener Depth

Maintaining a consistent depth of seeding is one of the most demanding tasks that any

no-tillage machine must perform. This is for several reasons:

- The surfaces of untilled soils do not get smoothed in the same way that tilled soils do.
- Untilled soils are often harder than tilled soils and therefore have less cushioning effect, causing more bounce of the openers, especially at higher speeds.
- The harder soils require greater downforces to push the openers into the ground. Variations in ground resistance therefore result in larger variations in seeding depth than where soils are softer and smaller downforces are used.
- The hardness or strength of untilled soils usually varies across a field as a result of natural settling of the soils. Regular pulverization by tillage virtually eliminates these differences in soil strength.
- No-tilled soils are often covered with surface residues, which might interfere with the opener's ability to manipulate the soil beneath it and further accentuate the surface roughness.

We shall consider each of the above aspects separately.

Surface following

Control of opener depth is partly a function of the opener and partly a function of the supporting drill or planter frame. With no-tillage, there is little or no opportunity to smooth the soil surface prior to drilling. No-tillage openers must therefore have superior surface-following ability compared with their counterparts for tilled soils. The extent of vertical mechanical movement alone should increase from approximately ± 75 mm (total 150 mm) travel for tilled soils up to ± 250 mm (total 500 mm) travel for untilled soils.

Depth-gauging devices

One of the important contributions that openers make to controlling seeding depth is the presence or absence of depth-gauging

devices (wheels, skids or bands), which 'track' the soil surface. Penetration forces are generally higher for untilled soils than for tilled soils. Further, the soil strength of tilled soils is usually quite uniform across the entire field as a result of the tillage process, while soil strengths of untilled soils vary quite widely on a metre-by-metre basis.

The result is that, if an opener relies solely on the penetration downforce reaching equilibrium with the soil's resistance to penetration in order to maintain a consistent seeding depth, as is common in tilled soils, seeding depths in untilled soil will vary just as widely as the soil strength. Consequently, any opener designed to operate at a consistent depth in an untilled soil will need at least some form of depth-gauging device. With such an attachment, a downforce can be applied in excess of that required to just attain target depth for that particular metre of soil. The additional force is carried by the gauging device without materially altering the depth of seeding.

Clearly, depth-gauging devices for untilled soils need to have the capacity to absorb quite large variations in applied force to operate satisfactorily in the inherent variability of such soils. Fortunately, untilled

soils also have an inherently high ability to withstand surface loading and avoid furrowing.

There are differences in the accuracy of depth-gauging devices according to how close to the point of seed release the gauging device is located. Obviously, being closer to this position results in more effective depth control. The effectiveness of the device may suffer if it is located too far from the seed deposition zone since, for example, it may register on a small hump when the seed is being released into a small hollow.

There are often mechanical limitations to where the gauging device can be located on an opener in relation to where the seed is finally ejected into the soil. Probably the nearest any opener designs have come to gauging depth precisely at the seed exit points are those on which a specially shaped semi-pneumatic tyre operates alongside (touching) the base of a disc at the point where the seed is ejected. Figure 8.1 shows such an arrangement.

Where possible, it is desirable to combine the depth-gauging function of wheels with the additional function of slot covering and/or closure, so long as one function is not markedly compromised by the

Fig. 8.1. Depth-gauging wheels located alongside the point of deposit of seed in a no-tillage opener.

requirements of the other. The depth-gauging wheels on the disc version of winged openers are located close to, but slightly rearward of, the seed-ejection zone so that they can perform these dual functions without significant compromise to either (see Fig. 4.27). The wheels in Fig. 8.1 do not perform a slot-closure function.

Almost universally, the gauging devices most favoured by opener designers are wheels, although skids and depth bands are also used on less expensive opener designs. The problems with skids in no-tillage are that they gather and block with residue and the higher down forces result in high wear rates as they slide along the ground.

Depth bands are sometimes attached to the sides of discs to limit the depths of their penetration, but the depth of seeding cannot be conveniently adjusted for different crops without removing the band and replacing it with a band of different diameter. They also tend to accumulate soil in the corner between the band and the disc, effectively increasing the diameter of the band and decreasing the seeding depth.

Gauge wheels are not without their problems either. Because wheels can only be attached by their axles, designers have to trade off the disadvantages of attaching them behind the opener against the disadvantages of attaching them beside the opener, where they might interfere with residue clearance and are unlikely to be able to function in a slot-closure capacity as well.

Since most no-tillage openers for residue conditions involve a disc of some nature as the central component, the disadvantage of locating gauge wheels behind the opener can also take on a new and additional dimension because the distance from the seed zone then increases by at least the radius of the disc. Consequently, despite their advantages for controlling depth of seeding, many no-tillage opener designs do not use gauge wheels at all. With those that do, most are located either beside the opener or partly beside and partly behind it.

A further complication arises when gauge wheels are required to perform the additional function of covering the slot. Wheels that only function for covering are called 'press wheels', those that only gauge depth are 'gauge wheels' and those that perform both functions are 'gauge/press wheels'.

Few openers have gauge/press wheels. One reason is that, for accurate depth control, the wheel should operate alongside the seed deposit zone, while for effective pressing the wheel should follow behind the opener. Furthermore, the wheel must roll on undisturbed soil to maintain depth control, while for useful slot pressing the wheel should be on either the loose soil over the slot or in the slot itself (see Chapter 5). These somewhat contradictory requirements often lead either to two separate wheels or to one of the functions being compromised in the interests of cost and residue clearance. In general, if the wheels on openers are supported by springs, they will probably be there solely for the press wheel function rather than also as gauge wheels.

The wheel on the opener shown in Fig. 8.1 is solely a gauge wheel. A smaller separate press wheel can be seen operating at an angle behind the disc.

An example of combined press/gauge wheels is shown in Fig. 4.27, where two wheels are used on either side of a central disc and slightly rearwards of the seed zone. The wheels are sufficiently wide to register on the undisturbed soil alongside the opener (the gauge wheel function) but are also angled so that they fold the flaps of residue and soil back over the inverted-T-shaped slot and gently press on it (the press wheel function). Inverted-T-shaped slots do not require pressing on the seed in the slot, so there is no disadvantage from only pressing on the top of the covered slot (see Chapter 6). The depth-control function of this opener is slightly compromised because the wheels are not located exactly at the seed release point, but there are other systems employed with this opener (see below) that more than compensate for this shortcoming.

The value of semi-pneumatic tyres

It is appropriate here to pay tribute to semi-pneumatic tyres, which are used on most modern press wheels and gauge wheels.

This often undervalued invention is one of the most successful adjuncts to agricultural machinery. Until semi-pneumatic tyres were invented, all gauge/press wheels were either rigid wheels or, at best, solid rubber, plastic or fully inflated tyres.

Because press wheels on seed drills almost invariably operate at least partially in a disturbed soil zone, even in no-tillage, they are very inclined to accumulate mud in damp conditions. Flexure is the most effective means for a wheel to shed accumulated mud. Fully inflated tyres under normal pressures and rigid wheels do not flex sufficiently to shed mud. Some no-tillage situations may require enough downforce for a limited flexing by fully inflated tyres.

A method had to be found to combine flexure with maintaining the accuracy of the gauging radius of the wheel, i.e. it had to be able to flex but still retain a predictable loaded radius, regardless of the loading on it. This is where semi-pneumatic tyres excel. Although they are hollow (in a multitude of cross-sectional shapes), there is no air pressure within them. Indeed, most have a small bleed hole so that air cannot be permanently trapped inside. The distance between the outer wall and the inner wall (against the rim) is relatively small. In operation, where the footprint zone contacts the ground, the outer wall collapses temporarily and presses against the inner wall and thence the rim. As it leaves the ground, the resilience of the rubber causes the outer wall to return to its original position. In so doing, the outer wall continually flexes in and out, which dislodges mud. The operating radius remains predictable so long as there is sufficient force applied to collapse the outer wall against the inner wall and rim in the footprint zone.

Walking beams

Another adjunct to no-tillage openers is the use of 'walking beams' for mounting the gauge wheels, such that a pair of wheels can independently move vertically while continuing to share the down pressure. These are simple mechanical leverage systems, which are applicable where there are at least two gauge wheels. A single linkage, pivoted at its centre, joins the mounting brackets for the two wheels in a pivotal manner. The two wheels find their own positions by equalizing the footprint forces about the pivoting walking beam. The equalized positions of the two gauge wheels constantly change as each wheel in turn encounters changes in the soil surface. As one wheel moves upwards, the other wheel moves downwards.

The point of this arrangement is that as each wheel encounters a small rise or hollow the whole opener is forced to rise or fall by only half the height of the rise or depth of the hollow. Thus surface roughness is smoothed by a factor of a half, which is important for no-tillage in the absence of general smoothing by tillage.

Figure 8.2 shows a walking beam arrangement for a pair of gauge wheels.

Fig. 8.2. A walking beam arrangement for equalizing the loads carried by two independent gauge wheels.

Disc seed flick

The tendency of double disc openers to flick seeds out of the ground arises when seeds become clamped between the two discs at or near the pinch point where they touch. At speed, as the discs move apart again behind this point, the clamping action, followed by sudden release of the seeds, may propel them upwards and rearwards, expelling them from the slot.

The problem is overcome by dropping the seeds behind the pinch-point zone and/ or by inserting covering plates in the zone between the two discs at their rearmost edges.

With all disc openers in sticky soils, at least one surface of the disc can become sticky. Seeds may either adhere to the disc and be lifted from the slot or soil may stick to the disc and carry seeds out with it.

With double disc openers, the seed is released against the inside surfaces of the discs that are not in contact with the soil. Thus, seeds seldom stick to the discs but soil sticking to the outside of the discs can seriously disrupt the integrity of slot formation and carry seeds, which have already been deposited, out of the slot (see Fig. 8.3).

With angled discs, the seed side of the disc is largely sheltered from soil contact, which helps to avoid seeds sticking directly to the disc.

The disc version of the winged opener has special subsurface scrapers designed to wipe sticking seeds off the disc below the ground (Thompson, 1993; Fig. 4.27).

Soil disturbance

With most disc openers, even when operating in non-sticky soils, a certain amount of soil disturbance occurs as the disc leaves the bottom of its rotation. This also occurs with hoe openers as the rigid shank moves forward in the soil. While seeds might not be flicked out of the soil by this soil movement, it may redistribute the seeds so that they occupy more random vertical positions within the soil than would otherwise be expected.

With some power till openers, the soil is deliberately disturbed and the seed is deposited into the rotor area while slot tilth is being formed, with the intention of thoroughly mixing the seed and soil. While this undoubtedly achieves its aim, the resulting variation in the depths of individual seeds does little for consistency of germination, emergence and maturity.

Residue hairpinning or tucking

The tendency of discs in any configuration to hairpin, or tuck, residue into the slot without actually cutting the residue often leaves the seeds embedded in or on this residue rather than in contact with clean soil. Many poor no-tillage plant stands have resulted from the hostile seed environment created by residue tucked directly into the seed slot. This occurs with both dry and wet residues, although the cause of the problem is different in the two cases.

With tough resilient residue, such as wet maize stover, the residue may quickly straighten out again after passage of the disc, in which case it may flick a portion of the seeds out of the slot. Figure 8.3 shows a soybean (*Glycine max*) seed that has been flicked completely out of a slot by a maize stalk after passage of a vertical double disc opener.

But, even if seeds are not flicked out, when they become embedded in dry hairpinned residue, they will not have effective seed–soil contact, this affects imbibition and germination. In wet soils, the fatty acids that are the products of decay of the residues cause seed and seedling mortality (see Chapters 6 and 7).

Opener bounce

Hoe-type and simple winged openers, which are under considerable downforce for penetration, often bounce in response to variations in soil strength, particularly at high speeds, disrupting the accuracy of seed ejection into the soil.

But disc-type openers are not immune either. Any opener is capable of leaving

Fig. 8.3. A soybean seed (lower centre) that has been flicked completely out of a no-tillage slot made by a double disc opener (from Baker, 1981a, b).

seeds on the surface after encountering stones in the soil. Hoe-type openers tend to push stones aside or flick them out of the ground, whereas disc-type openers tend to rise up and over stones and deposit seeds on top of the ground.

Seed bounce

As a result of high operating speeds and seeding into dry cloddy soils, large seeds often bounce upon contacting the soil. In severe cases, some seeds bounce right out of the slot.

The problem is accentuated with some air delivery systems when excessive delivery velocity of the air and seeds is used, which, combined with a high forward speed of the opener, may cause severe seed-bouncing problems.

Slot closure

Problems such as seed bounce can be largely overcome if the opener self-closes the slot immediately after it has been

opened to receive the seed. Some winged openers, slanted double disc openers and power till openers are examples of openers with good self-closing abilities.

Drill and Planter Functions

Downforce mechanisms

The most common downforce mechanisms for conventional drills and planters are springs. But springs change their loading forces in a linear fashion with changing length (i.e. they change their forces by the same proportion as their lengths change). This might be acceptable for tilled seedbeds because: (i) the loads applied are relatively small and the springs are not significantly compressed; (ii) the variations in ground surface and therefore spring lengths are relatively small; and (iii) springs are relatively cheap and trouble-free.

For no-tillage seedbeds, however, the opposite is true: (i) spring loads are high; (ii) surface changes can be quite large; and (iii) no-tillage drills are generally more robust and expensive. Because spring loads are high,

no-tillage drills tend to use either very heavy and unresponsive springs or smaller-section, longer springs compressed to short lengths. Because the changes in spring force are related to a spring's compressed length at the time, having a spring compressed to a short length to achieve opener penetration magnifies the force changes relative to length changes. Accordingly, some no-tillage drills and planters are designed with inordinately long springs (Fig. 8.4), or, alternatively, the springs are positioned near to the pivot points of the drag arms so that dimensional changes are minimized.

The force relationship with the length of springs applies equally well if the springs are arranged to be working in tension or in compression. Compression is more common, as it is difficult to overload a spring in compression compared with a spring in tension. For reasons of compactness, a few no-tillage drills and planters use springs acting in tension.

Either way, it is virtually impossible to maintain constant downforces with springs. A number of innovative designs have been used with the objective of reducing the shortcomings of springs. Some of these are illustrated in Figs 8.5 and 8.6. In Fig. 8.5,

the mechanical springs have been replaced with rubber buffers acting very close to the pivot (fulcrum) of the drag arms to reduce the required travel of the springs for any one change in position. Rubber acts in an almost identical manner to spring steel with regard to the force it exerts in relation to changes to its compressed length. But problems from prolonged exposure of rubber to ultraviolet light and retention of 'memory' after long periods of compression have made this an unpopular choice.

In Fig. 8.6, the designers have attempted to better equalize the spring forces across the drill, to accommodate, for example, passing over a hump on one side of the drill, by dividing the bar that compresses the springs into shorter articulating lengths. The effect is similar to walking beams described above for press wheels.

Another way to overcome the disadvantages of springs for downforce application is to provide the gauge wheels with very large footprints and then apply excessive downforces to ensure that the spring force is sufficiently large to allow for lengthening of the springs for the deepest hollow likely to be encountered by the openers.
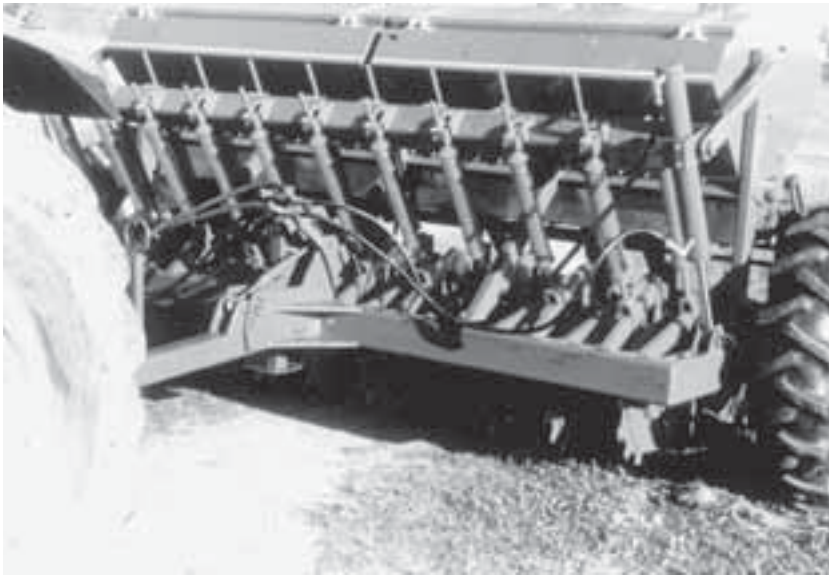
Fig. 8.4.   Long compression springs on a no-tillage drill.
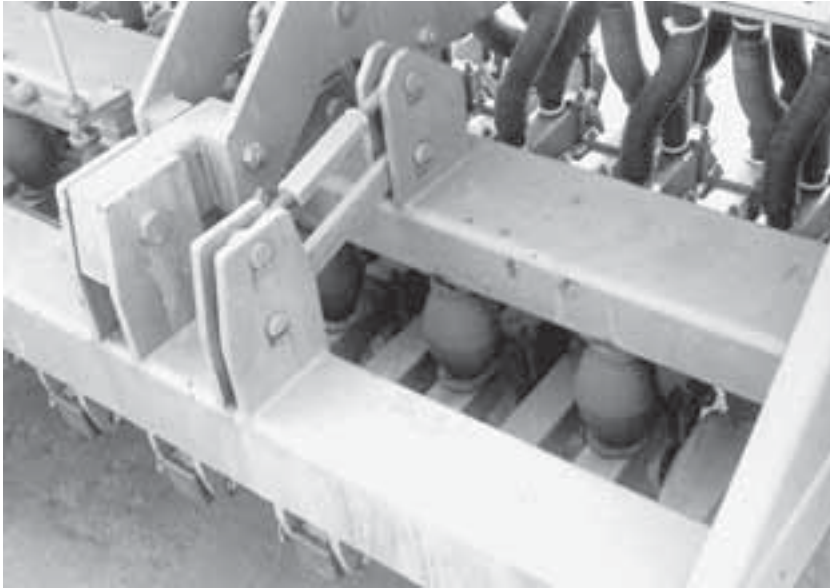
Fig. 8.5. No-tillage openers pressed into the soil with rubber buffers acting close to the fulcrum of the drag arms.

Fig. 8.6. A no-tillage drill with an 'equalizing' spring arrangement.

Figure 4.24 illustrates a design that has gone to the other extreme. In this case, the total vertical opener travel has been restricted by the use of spring tines that move largely horizontally (backwards) in response to increases in loading. The ground surface-following ability of such drills is poor, restricting their use to relatively smooth fields and/or seeds that are very depth-tolerant.

Regardless of the measures outlined above, springs are generally an unsatisfactory,

though still the most common, way of applying downforces to no-tillage openers. Characteristically, their shortcomings can regularly be seen in the field as too shallow drilling through hollows and too deep drilling over humps, leading to poor seedling emergence in both situations. Figure 8.7 shows the travel of a no-tillage opener with superior surface-following ability. Unfortunately, not all no-tillage drills are capable of achieving this degree of surface following.

Compressed air

Fortunately, there are alternatives to springs. The two most useful to date have been the use of air and oil (hydraulic) pressure, acting through rams or cylinders (Morrison, 1988a, b). The air pressure option uses large volumes of air acting on large-diameter cylinders attached to the drag arms. Because it is difficult to compress air to sufficiently high pressures to allow small-diameter cylinders to be used, there are

limits to the amount of downforce obtainable with compressed air.

On the other hand, air is free and large volumes can be compressed, with the result that changes in volume resulting from movement of openers up and down can be designed to have a minimal effect on the magnitude of the downforces. It should be appreciated that any gas under pressure has the same characteristics as mechanical springs. At any given temperature, a change in volume of the compressed gas will be linearly proportional to its pressure. With air, however, the volume can be made so large that pressure changes with movement of the openers can be minimized.

The biggest disadvantages of using air directly are the limited amount of pressure that can be practically obtained and the fact that the oxygen in air under high pressure can be explosive and that high-pressure air cylinders need to be independently lubricated, which is a problem in a semi-static system such as this. Lubrication is easiest where a continuous flow of compressed air

Fig. 8.7. An example of excellent surface following through a hollow by no-tillage openers (gas-over-oil downforce).

is used, such as with air tools. But in this case the compressed air is contained within a closed system, so lubrication is difficult.

Gas-over-oil systems

A more workable option has been to use oil in a hydraulic system in equilibrium with a compressed inert (non-explosive) gas (usually nitrogen) contained in one or more accumulators. This is referred to as a 'gas-over-oil', 'oil-over-gas' or 'nitrogen-cushioned hydraulic' system. The volume of gas in the accumulator(s), when the system is at its likely operating pressure(s), needs to be sufficiently large to reduce changes in pressure, arising from changes in opener position, to a minimum.

In reality, if the hydraulic cylinders on all openers are connected in common (parallel) to the hydraulic system, when one opener rises in response to a rise on the soil surface, another opener is likely to be falling in response to a hollow somewhere else across the drill or planter. Thus these two openers simply exchange oil between them without affecting the overall volume of oil or pressure of the system to any great extent.

Because of this, the need for large volumetric changes by the hydraulic system as a whole is much reduced. In contrast, mechanical springs can only work with individual openers unless a very complicated linkage is used to obtain some measure of combined action, as illustrated in Fig. 8.6.

Another advantage of the gas-over-oil system is that, if the individual hydraulic cylinders are of the double-acting type (i.e. they can be powered in both directions), these downforce cylinders can also be used to lift the openers for transport. This eliminates the need for a separate lifting assembly on the drill or planter.

The biggest advantage of either gas-over-oil or air cylinders is that they can be arranged so that the downforce on the openers remains virtually unchanged throughout the entire length of opener travel upwards and downwards because the force exerted by the cylinders remains constant throughout their entire stroke length. This in turn allows much greater vertical travel to be designed into the openers for surface following and depth control.

Figure 8.8 shows a no-tillage drill with a gas-over-oil downforce system sowing at the same depth on the top of an irrigation

Fig. 8.8. An illustration of the extraordinary surface-following ability of a gas-over-oil opener downforce system on a no-tillage drill.

border dyke as on the flat surface alongside, and even part-way up the slope. Tillage drills are never required to provide this much opener travel and many simple no-tillage drills do not achieve it either.

Automatic down force control (ADF)

A further refinement to the gas-over-oil system is to equip the drill or planter with a sensing device that measures the hardness of the soil as the opener travels through it. This signal is relayed to the hydraulic valving so that, as the soil hardness changes (which would otherwise alter the penetration depth of the opener), the oil pressure is automatically adjusted on the move to ensure that the openers get the correct amount of downforce to correctly maintain seeding depth in each metre of the field. This sophistication provides a fully automatic seeding depth-control capability, unparalleled with current technology.

Weights

One school of thought suggests that attaching weights to individual openers would be an effective way to ensure that each opener experiences the same downforce throughout its entire range of movement. But adding and removing individual weights for a multitude of openers on any one drill is impractical and would require the operator to carry surplus weights around in order to change the downforces for new conditions. It would also make changing the downforce on the move within a field impractical, but, then again, only the most sophisticated gas-over-oil systems with ADF allow this to be done.

Another downside to the use of weights is that, when an opener rises or falls, the inertia of the weight alters the effective downforce and that this inertia is highly dependent on the forward speed of the machine, which determines the speed of the rise and fall. For the technically minded, inertia is proportional to the square of speed in the direction of movement.

Where weights have their greatest use is for single-row drills, since many of the disadvantages above apply less to a single opener than to multiple openers on a larger drill and weights are often the cheapest and most effective option available where limited budgets apply (see Chapter 14).

Drag-arm design

The design and configuration of the drag arms that attach the seed opener to the drill frame are an important feature of drills or planters that have an impact on seed placement. A drill that has drag arms pivotally attached to the drill or planter frame will be designed to move the openers upwards and downwards to accommodate changes in the ground surface. This motion is provided either by a hinged attachment to the drill frame or by flexure of the drag arms themselves.

In the case of flexed drag arms, the whole drag arm must be constructed of spring steel. There are advantages in that this eliminates wearing joints, which, under the high forces involved in no-tillage, can become a maintenance problem. Such a desirable arrangement, however, must be balanced against the disadvantages of using mechanical springs as the downforce system in the first place and the difficulty in preventing the openers from also flexing sideways, which interferes with accurate row spacing.

With fully articulated (hinged) drag arms, the most common arrangement with conventional drills is to use a single arm pivoting on a simple unlubricated joint, as shown in Fig. 8.9. Because large forces are required to push openers into and drag them through the soil, there are quite large forces acting on the pivot, especially if the source of downforce is located close to the pivot itself. As a result, the wear rate within the pivoting mechanisms can be substantial.

This is an important issue with many seemingly advanced no-tillage machines. As new machines, they might appear to be of sound design. But as the pivoting joints wear, such machines soon provide poor seeding accuracy and become unserviceable, which creates an unforeseen cost penalty against no-tillage.

More sophisticated no-tillage drill designs provide pivots with lubricated and

Fig. 8.9. A simple single-pivot drag-arm arrangement (slightly modified from Baumer *et al*., 1994).

sealed bearings or heavy-duty bushings. While this adds to the initial cost, it can extend their service life to near that of the tractors that pull them.

Parallel linkages

To ensure correct functioning, some no-tillage openers must be maintained at a set angle to the horizontal in the direction of travel. Winged openers are a case in point. Such openers often employ two drag arms (upper and lower) arranged as a parallelogram in such a way that the horizontal angle of the opener remains unchanged throughout the entire range of its vertical travel.

The disadvantages of such an arrangement are the cost of the arms and pivots and the fact that four pivots have greater potential to create diagonal instability of the openers than one or two pivots if they become worn. To compensate, parallelogram drag arms are usually wider and more robust than single drag arms and utilize better-quality bushings or bearings in the pivots. Undoubtedly, they go another step towards perfecting precision seed placement in no-tillage, but to date they have only been included on advanced planter and drill designs.

Figure 8.10 shows a no-tillage opener mounted on parallelogram drag arms and the extraordinary range of travel provided by its gas-over-oil downforce system. The hydraulic cylinder is difficult to see but can be located from the position of the supply hoses (top right).

A variation on parallelogram drag arms is one where the parallelogram is designed to be deliberately imperfect (i.e. a trapezium). It is designed for operation with winged openers that are pushed into the ground with mechanical springs (Fig. 8.11).

Fig. 8.10. A winged no-tillage opener mounted on parallelogram drag arms and pushed down with a gas-over-oil system, showing its extraordinarily large range of vertical travel, which is important in no-tillage.

The objective has been to reverse the geometrical changes that occur with single-pivot drag arms, in which the angle of the wings normally becomes less in hollows and increases over humps. The effect is usually to accentuate the change in mechanical spring forces by drawing the wings into the ground more on humps than in hollows. But, in this design, the wing angle increases when the openers are in hollows and decreases when they go over humps. Since the steeper wing angle assists the opener to pull itself into the ground, the arrangement
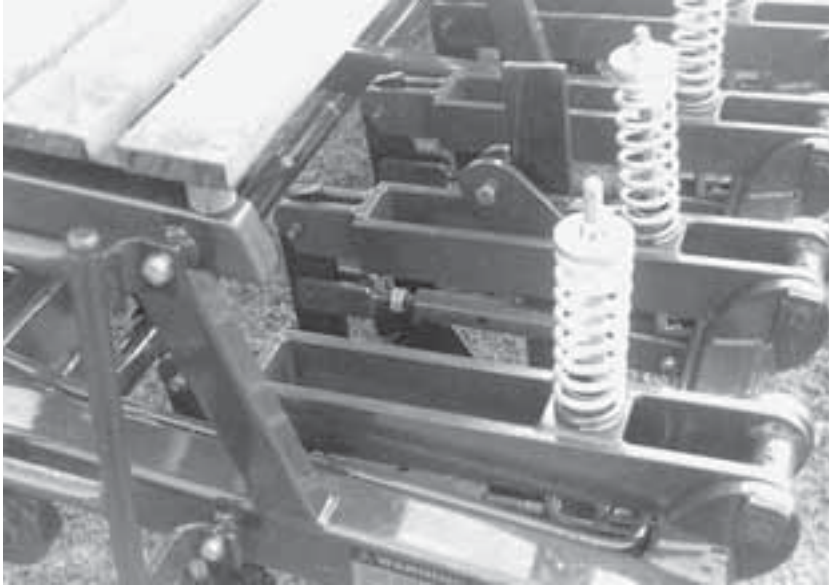
Fig. 8.11. A no-tillage opener in which a deliberately imperfect 'parallel' (trapezium) linkage is utilized.

goes some way towards countering the disadvantages of variable downforces with mechanical springs.

Comparisons

The authors compared the capabilities of two different no-tillage drills (both of which featured gas-over-oil downforce systems) in terms of their abilities to ignore surface irregularities (Baker and Saxton, 1988). Three types of tillage tool were used to cause surface roughness in an otherwise smooth untilled soil that had been chemically fallowed. The roughness treatments were: (i) chiselled with a shank chisel at 380 mm centres operating 200 mm deep, which left the roughest finish; (ii) cultivated with 250 mm wide sweeps operating 100 mm deep (the next roughest finish); (iii) disced once with a heavy double disc (the next roughest finish); and (iv) no tillage at all, which left a smooth surface finish. The drills used are labelled in the diagrams as 'Cross Slot' (disc version of winged openers that created inverted-T-shaped slots) and 'Double Disc' (vertical double disc openers that created V-shaped slots).

The plant stands from the two drills and four surface roughnesses are shown in Fig. 8.12, and the resulting yields of winter wheat are shown in Fig. 8.13. The 'Cross Slot' drill had higher plant counts and yields than the 'Double Disc' drill for all surfaces, but significantly more so for the rougher surfaces. The much heavier 'Double Disc' drill had difficulty maintaining depth control in the more loosely tilled, rougher surfaces. The no-tillage surface was easily penetrated by both drills, but the double disc openers 'tucked' considerable residue into the seed slot, which probably contributed to the lower stands with that drill in the very dry seeding conditions that were experienced (see Chapters 6 and 10).

Seed metering and delivery

With small seeds sown on a mass basis, such as grasses, legumes, brassicas and small-grained cereals, the seed metering devices on drills are designed to distribute a continuous trickle of seeds with no attempt to single, or handle individual seeds separately.
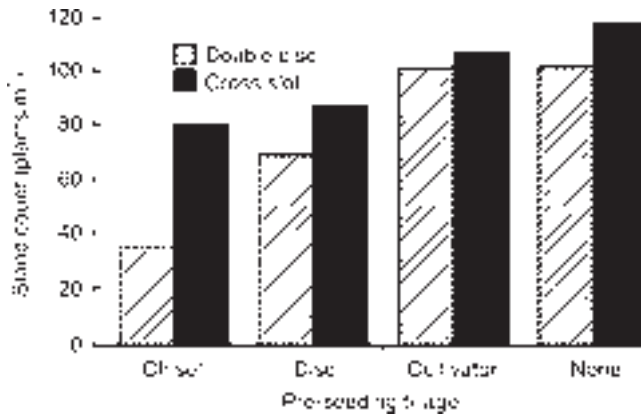
Fig. 8.12. The effects of surface roughness on wheat seedling emergence using two contrasting drills (from Baker and Saxton, 1988).
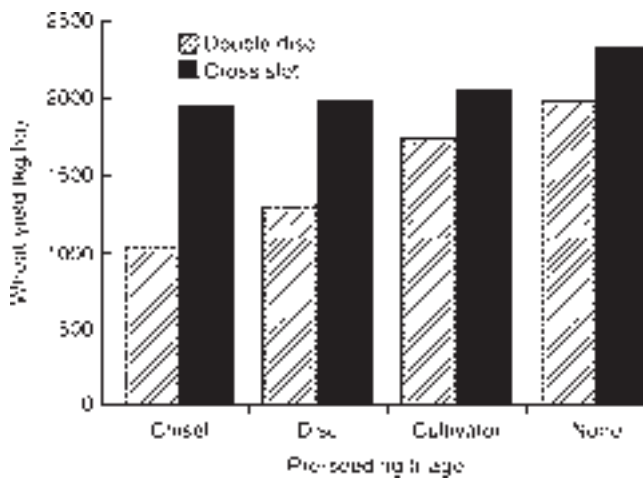
Fig. 8.13. The effects of surface roughness on yields of wheat using two contrasting drills (from Baker and Saxton, 1988).

As a result, such a trickle of seeds is largely unaffected by the length or shape of the delivery tubes that transport them from the seeder to the opener, so long as there is sufficient slope on the tubes for gravity to keep the trickle moving consistently or a stream of air to blow them along. Gravity delivery can be a problem when drilling up and down hillsides, where the drop tubes become too flat to maintain the seed flow. With air seeders, which substitute air flow for gravity, the air flow transports the seeds in a consistent manner to the openers and gravity plays only a minor role.

Seed metering and delivery are generally similar for no-tillage drills and drills used in tilled soils, with only minor differences. The seed metering mechanisms and delivery tubes can be expected to be common to both; however, the openers of no-tillage drills are often spaced further apart to clear residues and their vertical travel may be greater than for tilled soils. As a result, the seed delivery tubes may be longer and have further to span from the metering boxes to the openers, which may cause them to lie at flatter angles. Compensation for this loss of fall may involve raising the seed boxes higher on the drill or the use of multiple sets of seed boxes. Air delivery becomes an attractive option, since gravitational fall is then assisted by the air flow (see Chapter 13). An example of an advanced no-tillage drill with air-assisted seed and fertilizer delivery is shown in Fig. 8.14.

Fig. 8.14.   An advanced design of no-tillage air drill.

Precision seeders that select single seeds at regular intervals, such as maize, cotton, beet and vegetable planters, provide a different situation. Ritchie (1982) and Carter (1986) showed that, once a single seed is released from the metering mechanism into a tube, its pathway through that tube may be somewhat random. It will have a tendency to bounce from wall to wall and at each bounce it will lose an unpredictable portion of its drop velocity. Consequently, any two seeds seldom arrive at their destinations at exactly the same time intervals from when they were released from the metering mechanism.

Thus, even if a precision metering mechanism selects individual seeds at precise intervals, the precision of the intervals at which consecutive seeds reach the ground will depend on the pathways each follows after leaving the metering mechanism. It is even possible for a seed that took a more direct route down a delivery tube to catch up with and pass an earlier seed that bounced on its way down the same tube.

For this reason, precision seed metering mechanisms in tilled soils are located as close to the soil as possible so that the seeds have only a short drop, often without touching the sides of any tubes at all. Commonly, the distance of drop is about 50 mm and often less. This free-drop approach is possible only because tilled soils are prepared so as to have no surface residues and are as smooth and fine as possible, allowing the bulky seeding mechanism to pass close to the ground surface without the risk of blockage or damage.

In no-tillage, however, surface residues often protrude 300–500 mm above the ground, are variable in their nature and extent and are often quite woody. Vertical clearance is therefore necessary to avoid blockage. Further, there is little or no opportunity to smooth the surface of the soil. Consequently, no-tillage openers are larger and more robust than their tillage counterparts and the metering mechanisms have to operate higher above the ground. This necessitates seeds having to be delivered up to 600 mm from the metering mechanisms.

Free drop of seed is not an option over such a distance in no-tillage because of the effects of wind, slope and machine bounce.

The result is that, although the same precision metering mechanisms are used for tillage and no-tillage planters and the same numbers of seeds need to reach the ground in a given length of row in both cases, precise spacing between individual seeds under no-tillage is more difficult to achieve than in tillage.

Opener bounce is likely to be greater under no-tillage. Attempts to qualify the effect of openers' bounce were reported in 2004 (Anon., 2004). The tests found that four conventional vacuum-type precision seed metering devices of European origin were all adversely affected by shifting from a tilled soil surface to an untilled surface and that the adverse effects increased with increasing forward speed.

The key question of whether or not these sources of inaccuracy have a measurable effect on the final yield of large, compensatory-growth plants, such as maize, will continue to be debated (for example, there is mounting evidence that precision seeding depth may be more important than precision spacing, due to inter-plant competition) but the fact remains that precision spacing has become an important marketing objective for machines designed for tilled seedbeds. Since there is no known agronomic downside to precision spacing, it makes sense for designers of no-tillage planters to attempt to duplicate these levels of precision spacing as closely as possible if they want to persuade farmers to make the switch from tillage to no-tillage.

Summary of Seed Depth, Placement and Metering

1. Wheat seedling emergence in no-tillage may decline by approximately 4% for every 10 mm increase in drilling depth below 20 mm and even more beyond 50 mm.
2. Lupin seedling emergence in no-tillage may decline by approximately 17% for every 10 mm increase in drilling depth below 20 mm.
3. Red clover seedling emergence in no-tillage will decline markedly at drilling depths above and below 10–15 mm.

4. The ability of no-tillage openers to maintain a constant seeding depth is very important but very demanding.
5. Harder ground, rougher surfaces and the presence of residues on the surface accentuate the depth-control challenge under no-tillage.
6. Because of the large opener downforces required in no-tillage, seeding depth control often uses one or more gauge wheels on each opener.
7. Press wheels are often also used on each opener to cover the slot.
8. Few no-tillage openers have both gauge wheels and press wheels, and even fewer have combined gauge/press wheels.
9. Zero-pressure tyres are a useful adjunct to gauge wheels.
10. Walking beams are also a useful adjunct to gauge wheels.
11. Mechanical springs are a poor means of providing downforce for no-tillage openers because their forces change with length.
12. Compressed-air cylinders are sometimes used to provide downforce but are seldom a practical option.
13. Removable weights are useful on single-row no-tillage drills but are not practical for multi-row machines.
14. Gas-over-oil systems offer advantages by using hydraulic cylinders to both apply the downforce and lift the openers for transport.
15. Automatic downforce control systems offer further refinement to gas-over-oil systems by changing the downforces on the move in response to changes in soil hardness.
16. No-tillage openers should provide up to 500 mm vertical travel compared with a maximum of 150 mm for tilled soils.
17. Single-pivot drag arms on drills and planters are less useful in no-tillage than in tillage.
18. Parallelogram drag arms maintain the opener angle but are mechanically more demanding.
19. Lubricated bearings or bushes used for the pivots on no-tillage openers contribute to a realistic service life of machines that operate under difficult conditions.

20. The function of no-tillage openers in depositing seed consistently in an uninterrupted horizontal band in the soil is important.

21. The function of no-tillage openers depositing fertilizer in a separate band is also important, as discussed in Chapter 9.

22. The delivery of bulk-metered seeds to no-tillage openers is made more demanding by their large horizontal and vertical spacing.

23. Air delivery of bulk seeds to no-tillage openers offers advantages.

24. Single-seed spacing along the row from precision planters may be compromised in no-tillage because of seed bounce down long delivery tubes.

25. No-tillage openers may have special problems, such as seed flick, seed sticking to the disc, soil turbulence, residue 'hair-pinning', opener bounce, seed bounce and slot closure.