

13 No-tillage Drill and Planter Design – Large-scale Machines

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A no-tillage seed drill is no more nor less than a device designed to service the functions of its openers.

While most of the desirable functions of no-tillage drills and planters can indeed be related back to the desirable functions of their openers, other components and functions are also important. These will be examined in a general sense with no attempt to approve or disapprove design criteria for individual commercial drills or planters.

Manufacturers and designers who seriously consider the desirable functions of drills and planters and variations required to achieve these most often will present a range of design options. Consumers must then ascertain for themselves what represents the best value after having weighed the risk, performance and cost factors.

For example, drills for pasture renovation might not need to be as sophisticated as those to establish cash crops, because residue handling is seldom a high requirement with pasture establishment and there may be more time flexibility allowable in choosing an appropriate sowing date. This in turn permits a delay in drilling until favourable weather patterns arrive. The target sowing dates for cash crops, on the other hand, are often dictated by a narrow window of climatic opportunity or harvesting

and seldom allow the luxury of being able to wait very long for favourable conditions. Cash-cropping drills and planters, therefore, must function to their maximum potential with less dependence on weather and therefore need to be more sophisticated than pasture renovation drills.

This chapter considers large field-scale and tractor-drawn machines. The following chapter considers small field-scale and animal-drawn machines. In both cases we consider drill and planter design under several headings:

- Operating width.
- Surface smoothness.
- Power requirements.
- Downforce application.
- Transport considerations.
- Matching to available power.
- Storage and metering of product.

Operating Width

The most important factors that should influence the design width of no-tillage drills and planters are the total time available to establish a given crop and the tractor power available to pull the machines. Unfortunately, many converts from tillage to no-tillage expect no-tillage to achieve the

same rates of ground coverage as each of their previous tillage machines. Such expectations fail to account for the fact that no-tillage machines are only going to cover the field once and can therefore afford to operate at a slower rate of ground coverage. Because most no-tillage drills and planters are capable of operating at equivalent forward speeds to tillage machines, this means they can be narrower.

A sensible and practical comparison was made by an English farmer, who concluded that, so long as he could drill with his no-tillage machine at the same rate as he could previously plough, he would be gaining by adopting no-tillage. Despite such pragmatism, it is common to hear other farmers demanding that no-tillage machines must be the same width as conventional tillage machines. Some machinery designers accede to this request but in so doing are forced to select openers with low power demand. Almost invariably, the lower the power demand from no-tillage openers, the less work they do on the untilled soil and the greater will be the risk of biological failure.

For example, a farmer practising minimum tillage will cover the field at least twice and probably three times to establish a crop. If each of the machines used for minimum tillage (including the drill) was 4.5 metres wide, the effective working width would be 1.5 metres ($4.5 \div 3$). And yet many such farmers complain that a 3 metre wide no-tillage drill would be too narrow for them, even although once-over with a 3 metre wide drill would complete the whole job in half the time that three times over with 4.5 metre minimum-tillage machines could achieve. While seemingly simple, it is surprising how often this argument is voiced.

For 'diehard' tillage exponents, such an argument seems to be an excuse for avoiding the issue. For others already practising no-tillage with wide low-power-demanding drills, it reflects ignorance of the benefits that the more sophisticated no-tillage technologies offer (which are almost invariably accompanied by greater power demand).

While increases in both the power and downforce demand from openers translate into increases in tractor power and machine weight, these are relatively cheap and readily available inputs. Increases in biological reliability and crop yield from improvements in opener design are much more expensive and sophisticated inputs. Some operators choose to minimize power or weight requirements rather than maximize biological reliability. It is a matter of how individual operators approach the whole concept of no-tillage: whether they are yield-driven or cost-driven.

Those that see no-tillage as short-cutting tillage, but still regard tillage as the benchmark, will probably rate cheapness, maximizing working width and minimizing power and weight requirements as high priorities. Those that see no-tillage as the ultimate goal and regard tillage or minimum tillage as having been only interim learning steps (albeit practised for centuries) will take a different view. They will seek to maximize biological performance, almost regardless of cost, weight and width, and readily add the changes needed to their management practices. The world is full of people with both of these outlooks and is not likely to change in this respect.

The design and desirability of an operating width include a number of functions beyond that of the associated opener: power available, field topography, amount of product to be carried and field-to-field transport, to list a few. Each added function integrates into the overall design and machine width. Example machines shown in Figs 13.1 to 13.4 have a range of widths from 4 to 18 m, all outfitted with the same inverted-T opener but with widely varied configurations.

Surface Smoothing

The opportunity to smooth the ground prior to drilling is lost under a no-tillage regime. Thus, the drill or planter openers need to be able to faithfully follow significant changes in the surface of the soil without



Fig. 13.1. A 4.5 metre wide rigid-frame end-wheel no-tillage drill.

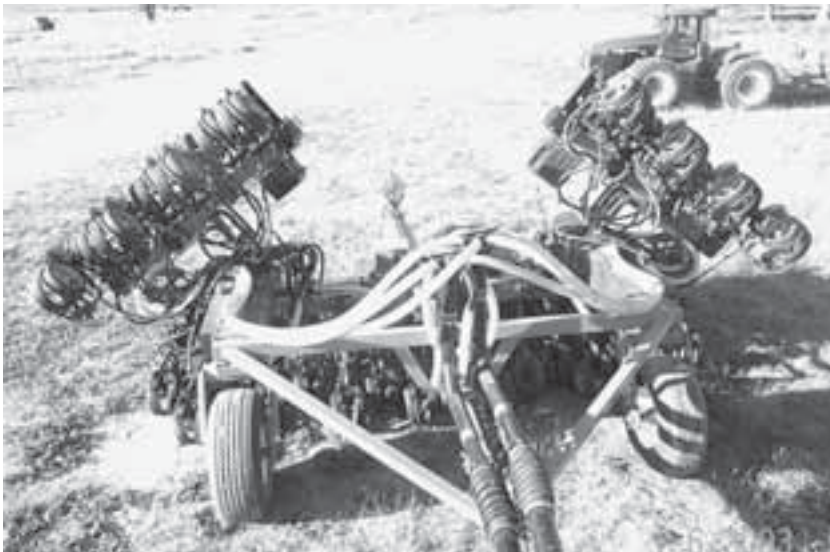


Fig. 13.2. A 12 metre trailed toolbar with folding wings for transport.

detriment to drilling depths or functions. This is a demanding requirement (see Chapter 8), but for general drill or planter design it places limitations on overall machine width and design considerations.

Six metres (20 feet) seems to be about the upper limit a machine can be expected

to span in a single frame and allow the openers to rise and fall sufficiently to follow each hump and hollow. Even then, unless the openers are pushed in with a downforce device capable of exerting consistent force as the openers move vertically approximately 0.4 metre (16 inches), some



Fig. 13.3. A 4 metre rigid toolbar that is lifted clear of the ground for transport.



Fig. 13.4. An 18 metre toolbar that is end-towed for transport.

inconsistent seeding depth will result from a 6 metre wide drill or planter. Where widths greater than this are required, multiple units or folding wings from a central unit should be considered. Even a 6 metre width with good opener surface-following ability is feasible only on reasonably flat

ground. A more universal size would be 4.5 metres.

Nor does it make any difference whether the openers are spaced 150 mm apart or up to 1 metre apart. Each individual opener must rise and fall in response to surface irregularities independently of

its neighbours. Its inability to do so will result in a missed row, regardless of how many other rows there are.

Because the micro-contour of the ground surface remains undisturbed, the gauge/press wheels of no-tillage openers must operate on a rougher surface than with tillage. Cushioning of this roughness can be achieved by springing the gauge/press wheels, but this virtually eliminates their gauging (or depth-control) function, since the relationship between the position of the wheels and the base of the slot (position of the seed) constantly changes when gauge wheels are sprung. Alternatively, mounting the wheels on walking beams effectively halves the magnitude of each surface irregularity, which will smooth the passage of an opener equipped with rigid or semi-pneumatic gauge wheels, without compromising their gauging function.

Then there is the question of speed. Obviously the faster the drill or planter is pulled, the rougher will be the ride. This is especially important with planters, because the accuracy of seed selection and final spacing is affected by the smoothness of ride. A speed that is acceptable for operating a given precision seeder on tilled soil may well be too fast when the same seeder is operated on untilled soil. This is a negative factor as far as no-tillage is concerned but must be balanced against the fact that several passes with tillage tools would have been necessary before planting was even attempted into a tilled soil. Therefore, if a slower planting speed is necessary for no-tillage planting, it will only reduce, not reverse, the advantages associated with no-tillage. And, with drilling of small seeds compared with precision planting of larger seeds, there are almost no speed restrictions. Indeed, some no-tillage drills operate at faster speeds than their tillage counterparts.

Power Requirements

No-tillage drills and planters require more power to pull them through untilled soils than do their tillage counterparts. This is

partly due to the fact that the openers are designed to break untilled ground and partly because the machines are heavier. Typical power requirements are 3 to 9 tractor engine kilowatts (kW) (4 to 12 horsepower (hp)) per opener (see later in this chapter). This amount of power also requires an associated traction increase; thus four-wheel-drive and tracked tractors are used more with no-tillage drills than with drills used in tilled seedbeds.

This power requirement places constraints on the number of openers that can be pulled with any given tractor. For example, a 25-opener drill operating on flat, light soil might require a tractor engine of approximately 150 kW (200 hp), while the same drill operating on silty and/or hilly soils or in dense sod might require a tractor with 50% more power.

Power requirements are also related to drilling speed. Some openers can operate satisfactorily at relatively high speeds (up to 16 km/h). Others should not be used above 7 km/h. The tractor power requirement will increase at higher speeds, but this will be put to good use by covering the field more rapidly.

Planters gain an advantage over drills with respect to tractor power requirement. The smaller number of openers on planters, due to their wider row spacing of up to 1 metre, means that tractor size will seldom be the limiting factor to machine size. Generally, it will be the surface-following ability of the openers that will dictate the upper limit of planter size, whereas with drills available tractor power is often the limiting factor. As a rough guide, for any given width of operation, a planter will require half the tractor engine power of a similar-sized drill.

Finally, drill width will be determined by a combination of opener number and row spacing. In general, crops benefit from closer row spacing under no-tillage than under tillage because of the improved moisture availability of untilled soils. On the other hand, the physical limitations imposed by residue handling dictate that no-tillage rows are seldom spaced less than 150 mm apart on drills.

Weight and Opener Forces

Each design of no-tillage opener requires a different downforce to obtain its target seeding depth. Required downforce is determined by a number of variables:

1. Soil strength, which determines the soil's resistance to penetration.
2. Soil moisture and density, which affect soil strength.
3. The presence or absence of stones and their sizes.
4. The presence or absence of plant roots that directly resist penetration.
5. The decay stage of plant roots, which is affected by the interval between spraying or harvest and drilling.
6. Operating speed, because openers penetrate better at slower speeds than at higher speeds.
7. The draught of the openers (their resistance to moving through the soil).
8. The attachment geometry of the openers to the drill frame, because, as an opener moves downwards into a hollow, the vertical component of pull increases, acting upwards, opposing and reducing the downforce pushing the openers into the soil.

Mai (1978) measured both the downforces and the draught forces, at 38 mm seeding depth at very slow speeds, of vertical triple disc and simple winged no-tillage openers operating in sprayed turf in a silt loam soil at two moisture contents. The results are shown in Table 13.1.

Data of Table 13.1 show that, while the vertical triple disc opener required about four times as much force to penetrate to 38 mm depth as the simple winged opener, it required 50% less force to pull it through the soil. The penetration action of the triple disc opener is one of wedging the soil sideways and downwards, accounting for its high downforce requirement. The winged opener, on the other hand, tends to heave the soil upwards, reducing its penetration force. In fact, soil acting on the upper surfaces of the inclined wings tends to draw that portion of the winged opener into the ground, although this is more than countered by the resistance to penetration of the pre-disc, the vertical shank portion of the opener and the lower frontal edges of the wings.

The vertical triple disc opener is comprised entirely of rolling discs. Once it has attained operating depth, the forces required to pull it through the soil are smaller than with the winged opener, which cuts roots and shatters a wider zone of soil than the triple disc opener as it moves forward. This is reflected in the downforce : draught ratios for the two openers, which averaged 0.65 for the vertical triple disc opener and 0.11 for the simple winged opener.

Not surprisingly, the wetter soil required less downforce and draught force from both openers than the drier soil, but the downforce : draught ratios remained reasonably consistent, regardless of soil moisture content.

Table 13.1. Downforce and draught requirements of two no-tillage openers.

	Vertical triple disc opener ^a		Simple winged opener ^b	
	23%	28%	23%	28%
Moisture content (g/g)				
Downforce (N)	882	842	221	203
Draught (N)	1684	1210	2096	1852
Downforce : draught ratio	0.53	0.70	0.11	0.11

Conversion: N (newton) = 0.2 lb force.

^aThe vertical triple disc opener had a flat 3 mm thick pre-disc of 200 mm diameter; the double discs were 3 mm thick and 250 mm in diameter.

^bThe simple winged opener had a flat 3 mm thick pre-disc of 200 mm diameter; the wings of the tine measured 40 mm across.

Baker (1976a), in three separate experiments, measured the downforces required for 38 mm penetration by a range of openers into a dry, fine, sandy, loam soil covered with sprayed pasture residue and at moisture contents ranging from 14.1% to 18.2% (g/g). The results are shown in Table 13.2.

Data of Table 13.2 show that the difference in downforce between the vertical triple disc and simple winged openers is slightly less than in Table 13.1, probably because of the softer (sandier) soil. The hoe opener was similar to the winged opener, suggesting that the draw-in effect of the wings on the winged opener played only a small role, since hoe openers do not have wings.

The angled flat disc opener required the least downforce of all openers tested, but the angled dished disc opener required more downforce than all other openers except the vertical triple disc, possibly because of the resistance to penetration of the convex (back) side of the angled disc.

For a drill or planter to operate, its weight or downward drag component must be sufficient to provide the required combined downforces of all its openers when operating in the worst (usually driest) conditions in which its openers can obtain seedling emergence. This concept is particularly important and often confuses would-be purchasers of drills when faced with the claims and counterclaims of manufacturers. For example, vertical double or triple disc openers are known to perform poorly in terms of seedling emergence in dry soils (see

Chapter 6). With few exceptions, drills and planters featuring such openers generally do not provide sufficient downforce (weight) for them to obtain drilling depth in dry soils. The drills therefore often appear to be relatively light in construction, giving the erroneous impression that they can penetrate the ground more easily than other drills, when in fact the reverse is true.

Winged openers, on the other hand, can tolerate very dry soils, in biological terms, so their drills and planters are often built to be heavy enough to force the openers into soils that might otherwise be biologically hostile. Thus, the overall weight of a drill or planter does not necessarily reflect the penetration requirements of its openers in any given soil. It may, in fact, reflect more the biological tolerance (or intolerance) of its openers to dry soils than anything else.

But there is more to forcing openers into the ground than just dead weight. Figure 13.5 shows four geometrically different arrangements for attaching openers to drill frames.

The first (and simplest) arrangement is to fix the openers rigidly to the drill frame, preventing articulation between the two. This gives the drill a very poor ability to follow ground surface changes, but the downforce provided for each opener will remain reasonably constant and largely predictable.

The second arrangement uses a length of heavy spring steel to: (i) introduce a separate drag arm between the drill chassis and the opener; and (ii) provide limited movement between it and the drill frame. To accomplish the second function, the upper

Table 13.2. Downforce requirements of a range of no-tillage openers.

	Vertical triple disc ^a	Simple winged ^b	Hoe ^c	Angled flat disc ^d	Angled dished disc ^e
Downforce (N)	770	281	263	133	445

Conversion: 1 N (newton) = 0.2 lbs force.

^aVertical triple disc design was as for Table 13.1. The value is the mean of three experiments.

^bThe simple winged design was as for Table 13.1. The value is the mean of three experiments.

^cThe hoe opener had a flat 3 mm thick pre-disc of 200 mm diameter, and the tine was 25 mm wide. The value is the mean of three experiments.

^dThe angled flat disc was 3 mm thick and 250 mm in diameter. The value is for a single experiment.

^eThe angled dished disc was 2 mm thick and 250 mm in diameter. The value is for a single experiment.

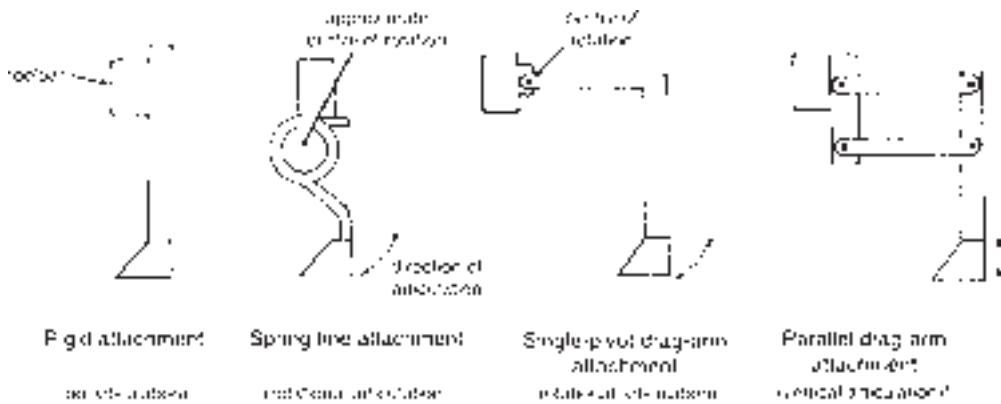


Fig. 13.5. The geometrical options for attachment of drag arms to a no-tillage seed drill. *Opener also moves forward, but since the whole machine is moving forward anyway this is ignored as it does not affect the function of the opener in any way.

portion is extended and often coiled several times to increase its flexibility. In operation the soil drag on the opener tends to cause the drag arm to pull backwards as well as deflect upwards, but the actual displacement in either direction is relatively small. This means that the point of action of the applied downforce in the soil remains relatively constant in relation to the drill frame, and there is therefore little change in downforce as the openers traverse undulations in the ground surface.

This design limits their ability to faithfully follow variations in the ground surface. In addition, many similar designs allow the openers to wander sideways, with the result that inter-row spacing varies somewhat, although this also gives them an ability to handle large surface stones with less blockage than either rigid openers or drag arms that move only in the vertical plane.

The third arrangement is commonly used for conventional drills for tilled seedbeds and has been simply transferred to many no-tillage drills with adjustments only for robustness and the magnitude of the applied downforces. It consists of a pivot-mounted single drag arm, which is pushed down from above or sometimes pulled down from beneath. The opener cannot deflect rearwards, only upwards and downwards in a limited arc about the pivot point between the drag arm and the drill frame. Because the force applied by the

tractor to create forward movement (drag force) acts through this pivot point and is opposed by the resistance of the opener at the point of soil contact, these forces can be resolved into their vertical and horizontal components by triangulation.

Figure 13.6 shows the resulting force diagram. The drag, or draught force applied by the tractor is opposed by the soil resistance to forward movement (P) through the soil. This is shown as the horizontal component of pull (H) in the diagram. The vertical component of pull (V) is derived from the resultant line of pull (R) which passes through the point of attachment of the opener to the drill and the centre of resistance (X) of all soil forces, which is the point of equilibrium of all soil resistance forces on the opener and is located somewhere beneath the soil. The vertical component of pull (V) acts upwards and, together with the vertical force arising from the soil's resistance to penetration, has to be overcome by the net vertical downforce (D), which is applied separately by springs or other means on the drill (not the tractor) for the opener to remain in the ground.

All of these forces find an equilibrium, but a problem arises when the position of the opener changes relative to the drill frame. For example, as the opener passes into a slight hollow and moves downwards (relative to the pivot point or drill frame), the horizontal component of pull (H) may

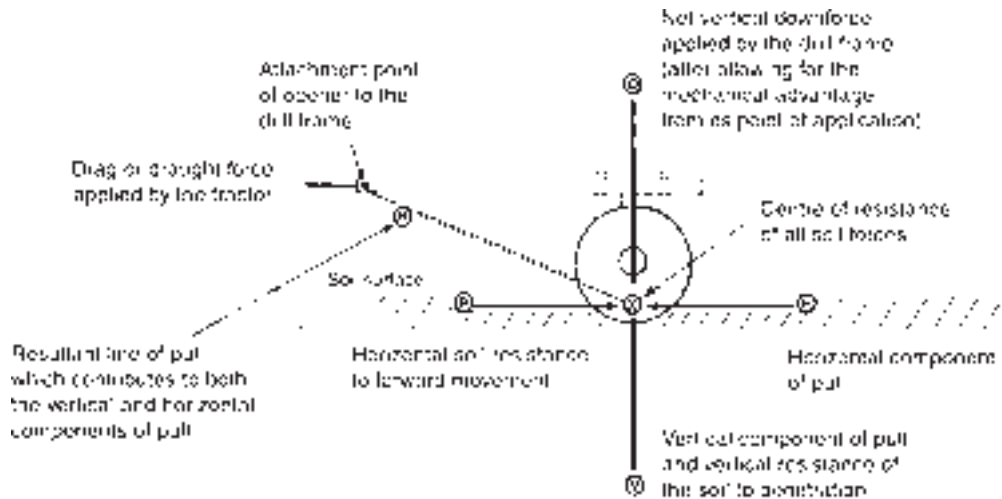


Fig. 13.6. The distribution of forces acting on a no-tillage opener as it is pulled through the soil.

not change, but the vertical component of pull (V) will increase because the resultant line of pull acting through the pivot point (R) will have become steeper.

This means there will then be a greater upward force opposing the net vertical downforce (D) on the opener, which at best remains constant, resulting in shallower drilling. It would be a big enough problem if the applied downforce did in fact remain constant, but, where the mechanism of downforce application on the drill is commonly a spring, the downforce will actually decrease somewhat as the opener moves downwards because the spring lengthens. The net effect is a significant reduction in the net vertical downforce (D) applied to the opener, resulting in shallower drilling for that portion of the field.

The opposite effect occurs when an opener passes over a hump. Characteristically, openers with this common geometrical arrangement drill ‘hollows’ too shallowly and ‘humps’ too deeply.

However, the problem does not stop there. If the soil resistance to forward movement (P) increases because the drill encounters an area of harder soil, the magnitude of the resultant line of pull (R) will increase, even though its slope may remain the same. This in turn will increase the vertical component of pull (V), which, unless it is

compensated for by an increase in net vertical downforce (D), will also result in shallower drilling.

In reality, both the soil surface and resistance to forward movement of individual openers continually change under no-tillage. Therefore, so too does the vertical component of pull, causing penetration variation.

The fourth arrangement (Fig. 13.5) is common on precision planters and more sophisticated no-tillage drill designs. Here the single pivoting drag arm used in the third arrangement is replaced by two parallel drag arms of equal length arranged as a parallelogram, illustrated on the right of Fig. 13.5. The objectives of this configuration are fourfold:

1. To maintain a predictable relationship between several components on an opener assembly. Some planter openers, for example, have up to six separate components following one another in a fixed relationship. If the assembly were mounted on a single pivot drag arm (Figs 13.5 and 13.6) and moved in an arc as it rose and fell, the vertical relationship between the forward and rear components would alter appreciably as it travelled vertically.
2. To maintain a given approach angle of critical components to the soil, regardless of the vertical position of the opener assembly.

Winged openers, for example, have soil wings that slope downwards towards the front at an angle of 5–7° to the horizontal so that they can operate at shallow depths with the wings still beneath the ground. If the opener were mounted on a single-pivot drag arm, the preset wing angle would need to be increased to about 10° to ensure that a positive wing angle remained at the bottom of the arc of movement. But in the mid-position an angle of 10° would limit the shallowness of drilling because the wings would break through the surface of the soil.

3. To reduce the magnitude of the forces opposing the downforce. Although a parallelogram arrangement will have little or no beneficial effect on the vertical component of pull opposing the downforce, there is yet another force that also opposes the downforce on single-pivot drag arms. This is the rotational force arising from the horizontal soil drag acting rearwards on the base of the opener (which is always positioned lower than the pivot itself). With a single-pivot drag arm arrangement, this rotational force causes the opener to attempt to rotate upwards, regardless of the opener position or angle of the drag arm, and opposes the downforce. The actual magnitude of this opposing force is somewhat self-cancelling because, if the opener rotated upwards, the soil drag would then be reduced because the opener would be drilling more shallowly. On the other hand, when the arms are horizontal in a parallelogram arrangement, this rotational force is eliminated altogether and has no effect on the downforce. Most drills and planters are designed so that the drag arms are nearly horizontal in the normal drilling position.

4. To facilitate the design of long and short drag arms without changing the position or geometry of the downforce application. The force mechanics of parallelograms is such that, if a downforce is applied part-way along one of the horizontal arms, there will be a resulting vertical downforce at the rear pivots. Further, if a rigid horizontal frame is attached to these rear pivots, the same downforce will be applied at any point along this rigid frame. Since an opener attached to the rear pivots of a

parallelogram acts as a rigid horizontal frame, this principle applies to openers mounted on parallelogram arms.

In drill designs, this allows openers of different lengths to be attached to parallelogram linkages in order to create stagger for residue-clearance purposes, and each opener will experience the same downforce as its neighbour.

Although the best of the innovations and geometric arrangements discussed above go a long way towards ensuring that no-tillage openers receive constant downforces throughout their extended ranges of travel, it should be emphasized that the magnitude and direction of the main opposing forces (i.e. the upward vertical components of pull and soil resistance) vary with soil conditions and the position of the opener at any one point in time and are therefore seldom constant. Thus, no geometrical arrangement so far devised has the ability to maintain a truly consistent net penetration downforce on an opener.

Re-establishing Downforce

An adjunct to the general downforce requirements of no-tillage drills and planters is the range of methods used to ensure that a drill or planter re-establishes the downforce to its preselected level after the openers have been raised from the ground for transportation and/or cornering. Repetitive raising and lowering of the openers are more common in no-tillage than in tillage because turning sharp corners with the openers engaged is difficult in untilled ground. Some of the systems used are:

- 1.** Manual return to a guide mark. Where a drill or planter is designed to raise the openers using one or more hydraulic rams on the machine frame, the resetting of those rams to their original positions is achieved by the operator watching a guide mark to indicate where the ram(s) had extended or contracted to previously and stopping the cycle at that point. The potential exists for operators to forget to watch the guide mark

and, in any case, such a repetitive manual task adds to operator fatigue. On the other hand, this system allows the downforce on all openers to be altered by the operator without leaving the tractor seat.

If a drill or planter is three-point linkage-mounted to the tractor or has a separately controlled set of transport wheels, the depth adjustment is usually achieved by changing a mechanical linkage, a screw of some description, or the pressure in a second independent hydraulic system. This adjustment remains unaltered during drilling and transportation cycling. Return of the machine to the ground after transportation automatically re-establishes the magnitude of the original downforce, since nothing will have been altered in that respect during transportation. While this reduces operator fatigue, alterations to the downforce often require the operator to leave the tractor.

2. Return to an automated stop or pressure. Where a drill or planter is designed to raise and lower its openers hydraulically, an adjustable hydraulic or mechanical control valve can be positioned on the machine so that a predetermined mechanical movement or oil pressure build-up will trip the valve and halt the hydraulic system at any desired position commensurate with a given downforce. While this increases convenience for the operator, a time delay still results while the tractor hydraulic system moves the ram to its predetermined position, and alterations to the magnitude of the downforce still require the operator to dismount from the tractor.

One tractor manufacturer for many years provided a pressure-modulating system on the internal hydraulic source within their tractors. This system allowed the operator to vary the hydraulic pressure from the tractor seat, useful for pressurizing rams on drills or planters. Repeatability of the system simply relied on the setting of a stop on the tractor's hydraulic controls. The operator returned the lever to this position after actuating the lifting and transport cycles of the hydraulic system.

3. Automated return. A hydraulic 'memory valve' is supplied on some no-tillage drills and planters that utilize the same

hydraulic rams for both downforce and lifting. The memory valve increases the repeatability of settings during frequent transportation and drilling cycling by automatically storing the downforce oil pressure in the oil-over-gas nitrogen accumulator(s) when the lifting (transport) cycle is actuated. Upon return of the openers to the ground, the memory valve automatically and instantly returns the original oil pressure to the downforce system without further attention from the operator. This greatly increases the speed of cycling from drilling to transport modes, and vice versa, which is important for field efficiency, operator fatigue and operator accuracy. The operating down-pressure can be changed at any time from the tractor seat.

One of the major problems with all no-tillage drills is that the magnitude of the forces involved for downforce and draught places unusually high stress loadings on drag arms, openers and their supports. This problem is exacerbated when drills or planters are required to operate around corners. The more durable designs have used ball or roller bearings in the drag-arm pivots, where simple bushings would usually have sufficed for the same function with conventional drills in tilled soils.

Unfortunately, some of the previously used simple designs of conventional drills have also been extended to less expensive no-tillage drills. These units often experience early failure of components and loss of accuracy. For example, as pivots of drag arms become prematurely worn, openers are difficult to maintain in vertical or tracking alignment, resulting in inaccurate depth of seeding and uneven row spacing. The frequency of breakages increases and residue handling often suffers. These machine failures cause frustration for the operators and result in a decline of enthusiasm for no-tillage farming.

Wheel and Towing Configurations

A major distinguishing feature of no-tillage soils compared with tilled soils is their

long-term ability to sustain wheel traffic without compaction damage and their resistance to surface damage from the scuffing caused by machinery wheels and tracks. Even when compaction does occur, as the populations of soil fauna and bacteria return to sustainable levels in response to decreased tillage disruption and increased organic matter, the natural restorative processes of living soils soon ameliorate most problems.

No-tillage drills and, to a lesser extent, planters are inherently heavier than their tillage counterparts, but it is seldom necessary to increase the footprint area of their wheels, tyres or skids on a proportional basis to their weight because of the increased load-bearing strength of the soils on which they operate. None the less, there is little point in subjecting even untilled soils to footprint pressures from drills that are significantly in excess of the tyres on the tractors that pull them. Tractor tyres usually exert footprint pressures in the range of 50–85 kPa (7–12 psi) and tracks in the 30–50 kPa (4–7 psi) range.

As with conventional drills and planters, there are several optional wheel configurations. Some of these, with their attributes and limitations, are outlined below.

End wheels

End-wheel designs, as the name suggests, have wheels positioned at either end of the drill or planter chassis. Some planters, because of their wide row spacing, have the wheels positioned between the rows some distance from the ends of the machines. This reduces side forces during cornering and allows two or more such machines to be conveniently joined together end to end.

End-wheel designs are suitable for machines up to 6 metres in width. The end wheels provide excellent manoeuvrability and stability on hillsides and are usually less expensive than other options. Most designs use single wheels on each end of the machine, making them unsuitable for end-towing for road transportation without the addition of special transport wheels. Some designs use paired wheels on

walking beams, which double the footprint area, reduce bounce and provide an opportunity for convenient conversion to end-towing.

End-wheel drills and planters are not well suited to the joining of several units together side by side. Where joining machines is contemplated, it is necessary to arrange the multiple units in an offset pattern from a common and separate towing frame (as illustrated in Fig. 13.7). On the other hand, no-tillage farming saves so much time that had been previously devoted to tillage before drilling that the need for wide, multiple drills and planters is reduced considerably.

Fore-and-aft wheels

Fore-and-aft wheel configurations involve one or more self-steering wheels on either the front or rear of the machine and at least two fixed wheels on the opposite end. The configuration reduces the lateral distance between the wheel positions, permitting wider machines to be designed than with end wheels. Because there are no wheel structures on the ends of the machines, multiple units can be conveniently joined, as illustrated in Fig. 13.8. Such multiple arrangements need a much less complicated common towing facility than do multiple end-wheel arrangements.

Another arrangement permits two drill units to be used either as a narrow-row drill or as a wide-row planter. The row spacing of each unit is fixed to the desired spacing for the wide-row planter configuration and two such units are arranged end to end to produce a double-width planter (see Fig. 13.9). When narrow-row drilling is required, the two units are arranged in tandem fashion, with the rows of the rear unit splitting the rows of the front unit, thus halving the row spacing.

Of course, for this convenient arrangement to be functional, the seed metering mechanisms must be capable of sufficient accuracy to satisfy the needs of both the planter and the drill. Very few seeders are capable of this degree of flexibility. Either duplicate seeders are used (which is



Fig. 13.7. End-wheel drills arranged in an offset multiple arrangement.

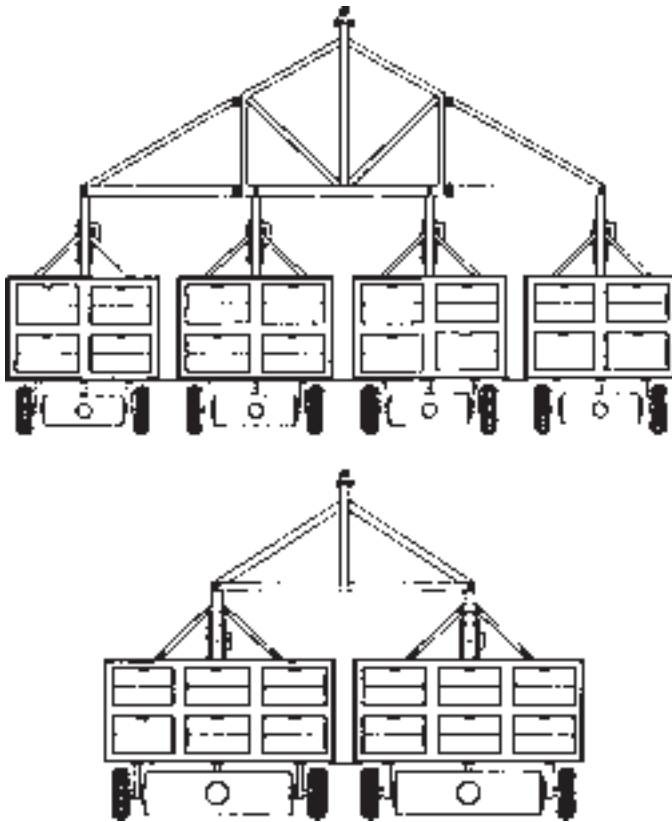


Fig. 13.8. Fore-and-aft wheel drills arranged for multiple unit operation.



Fig. 13.9. Two-wide row units arranged in tandem to produce a drill with half-row spacing.

expensive and mechanically complicated) or one or the other of the two seed metering functions is compromised.

The options for transportation conversions with fore-and-aft wheel configurations are many and varied. An example of a convenient arrangement for a three-unit ganged drill is shown in Fig. 13.10. The two outer drill units fold forwards after the whole machine is raised clear of the ground for transportation. Other options include folding the outer units upwards, but this option is limited to air seeders and planters with lockable lids on their product hoppers to avoid spillage. The product hoppers on air seeders are located on the central drill unit and not involved in the folding process.

Yet another arrangement for transporting two fore-and-aft wheel drills is shown in Fig. 13.11.

Matching Tractors to Drills and Planters

In conventional tillage, tractors are usually selected to match the heaviest power-

demanding implement(s) used, from primary tillage (usually ploughing) to drilling. Since drills and planters in conventional tillage are among the least power-demanding implements, tractors are seldom selected to match drills and planters, or vice versa. Indeed, often a smaller available tractor than the main tillage tractor(s) is used for drilling and/or planting.

In no-tillage farming, the sprayer is the only light power-demanding implement in the system. Drills and planters are the heaviest power-demanding implements, and this power requirement may exceed the power required by any one of the tillage implements it replaces. This is not to say that no-tillage is energy-inefficient. On the contrary, this single input of energy is several times more energy-efficient in terms of total litres of tractor fuel used per sown hectare than the sum of all of the multiple smaller inputs of energy during tillage.

With planters, the maximum number of widely spaced rows to be sown by any one machine seldom exceeds 12. The power requirement for such machines is therefore less likely to be a limiting factor, even under no-tillage, than with no-tillage drills, which may have up to 50 such openers.



Fig. 13.10. A folding arrangement for multiple drills.

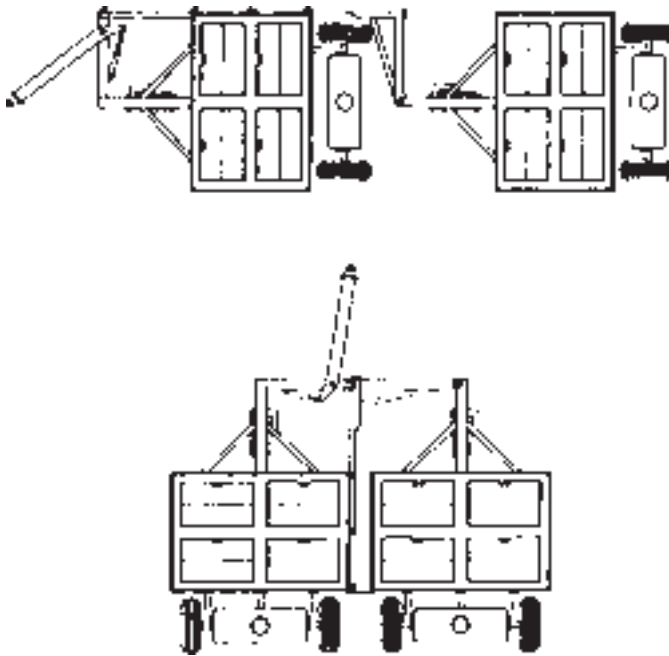


Fig. 13.11. A towing arrangement for two fore-and-aft wheel drills.

First-time no-tillage farmers must often change their evaluations to correctly match tractors with drills and planters. Difficulties arise in several ways:

1. Farmers are not used to thinking of drills in terms of their power requirements.
2. There is little information available to inform farmers about the specific power

and/or draught requirements of different drills and/or openers.

3. Because no-tillage drills are often considerably heavier than their tillage counterparts, some of the power requirements will be needed to move the machine weight, especially on hilly land.

4. Since no-tillage drills and planters break untilled and often hard ground, they are more sensitive to speed than tillage drills as far as power demand is concerned.

5. On the other hand, because no-tillage is so much more time-efficient than tillage, high drilling/planting speeds may not be important.

6. Often, in no-tillage, the traction of a tractor will be more important than its available engine power. Thus, four-wheel-drive and tracked tractors are likely to become more useful.

7. Because turning corners while drilling with no-tillage drills is more difficult than with tillage drills, more fields are drilled in strips ('lands'). This demands sharp turning on headlands or looped turns on corners, requiring a tight turning-circle capability from the tractor and drill.

8. The annual tractor use for drilling/planting is likely to be reduced substantially under no-tillage compared with tillage. This means that total annual tractor costs are lower, tractors last longer in terms of time and replacement scheduling, but the actual hourly cost may be increased.

9. The necessity to continuously monitor drill/planter functions from the tractor seat is increased, because under no-tillage a farmer has but one chance to get everything correct. Tractors therefore need to be electronically as well as mechanically compatible with their drills and planters.

10. The soil in wheel tracks under no-tillage is often loosened because of the high demand for traction, whereas under tillage the result is almost invariably compaction in the wheel tracks. Tractors working near the traction limit in no-tillage will cause more soil loosening and therefore greater differences of opener performances between those within and outside the wheel track areas.

It is difficult to generalize power requirements of no-tillage drills because they have a large range of weight and draught. Ignoring the weight of the drill, some generalizations can be made about the power requirements of individual no-tillage openers from Table 13.1. While draught requirements for only two openers (triple disc and winged) are shown, these two designs are near either end of the range of draught requirements for no-tillage openers. Thus, their requirements may reflect a range of power requirements for no-tillage openers in general.

The power required to pull an opener through the soil is given by the expression:

$$\text{power (kW)} = \frac{\text{pull (newtons)} \times \text{speed (km/h)}}{3600}$$

or

$$\text{power (hp)} = \frac{\text{pull (pounds)} \times \text{speed (miles/h)}}{375}$$

It can be seen in Table 13.1 that at a speed of 5 km/h (3 mph) a single triple disc opener would require up to 2.3 kW (3 hp) and a single simple winged opener up to 2.9 kW (3.8 hp). At 10 km/h (6 mph) the respective power requirements would be 4.6 kW (6 hp) and 5.8 kW (7.6 hp).

In general, the power requirements of no-tillage drills and planters might range between 2 and 6 kW (2.5 and 8 hp) per opener, depending on the drilling speed, the ground conditions, the soil type, the density and state of decay of root material in the soil, the contour of the field, the method of working the field, the design of the opener and the weight of the machine. Allowing for a tractive efficiency of 65% by the tractor, this would require a tractor engine size range from 3 to 9 kW (4 to 12 hp) per opener, which closely matches field experience.

Product Storage and Metering

For handling products such as seed, fertilizer and insecticides, the most distinguishing feature of no-tillage drills in comparison with their tillage counterparts arises from

the need for openers to be spaced widely apart to clear surface residues. With planters, the openers are spaced widely apart, usually in a single line, anyway. So no major distinction is made in this regard between planters for tillage and for no-tillage.

With drills, the wider-than-normal opener spacing is usually achieved by increasing the longitudinal staggering of alternate openers, since the row spacing between openers cannot be altered without affecting the agronomy of the crop. This increase in longitudinal spacing results in long seed delivery tubes and shallow drop angles between the hoppers and openers for these tubes if supplied by a single hopper. Such shallow angles interrupt normal gravity flow, especially on hilly land. The problem is overcome in one of three ways:

1. Raising the product hoppers to greater heights above the openers so as to increase the angles on the delivery tubes (Fig. 13.12).
2. Doubling the number of hoppers so that each hopper is positioned over the openers at normal height and delivery tube angles.
3. Utilizing air delivery of product to the openers from a central hopper (Fig. 8.14).

There are arguments for and against each option. Doubling the number of hoppers, for example, adds to the capital cost of the drill but increases the amount of product that can be carried and therefore reduces the number of times the machine needs to be out of service for filling, as well as temporarily adding to the weight of the machine, which may help with downforce. Air seeders are inexpensive but larger designs carry the weight of the product on a separate axle where neither it nor the weight of the hoppers themselves contributes to the overall weight of the machine to assist downforce.

High hoppers are inexpensive but are difficult to fill and contribute to drill instability on hillsides. On very steep hills, at least one drill that carried liquid fertilizer tanks provided a facility to slide the tank to the uphill side of the drill to assist stability (Fig. 13.13). There are no known designs that shift dry hoppers on the move.

Because the surface residues common in no-tillage provide a habitat for pests (and their predators), it is often necessary to apply insecticide(s) with the seed at drilling. Thus, dry granule hoppers and/or liquid insecticide facilities are common on



Fig. 13.12. A no-tillage drill with elevated product hoppers.

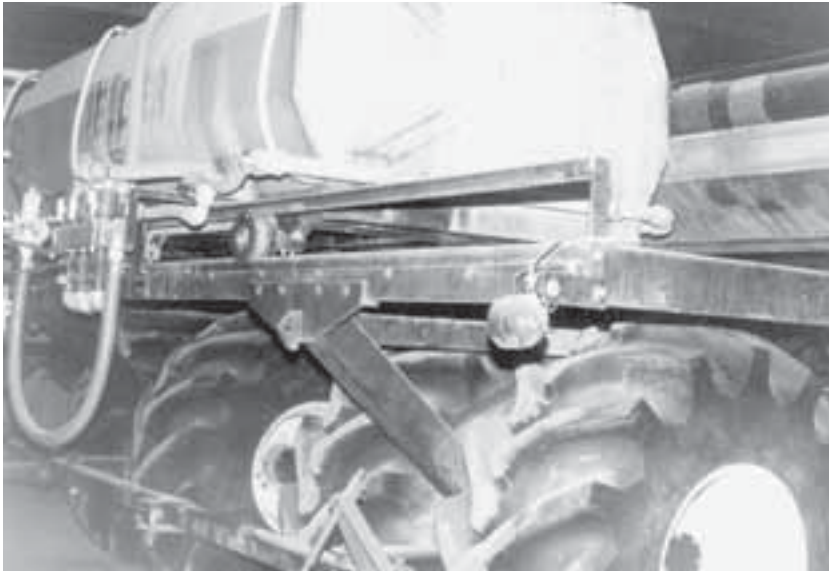


Fig. 13.13. A no-tillage drill with sliding liquid fertilizer tank.

some no-tillage drills and planters. Some planter manufacturers have cooperated with chemical manufacturers to provide closed transfer systems for insecticides. This provides for safer handling of chemicals, although operators need to be cautious of pesticide residues on drill and planter components during maintenance.

The concept of drilling and spraying simultaneously by mounting a spray boom on the drill or planter was investigated in New Zealand. While such an achievement would have made no-tillage a truly one-pass operation, the idea was judged not practical for several reasons:

1. It was possible to drill on days on which it was not wise, or possible, to spray because of wind or rain that might otherwise compromise the efficacy of weed and pest control formulations. By restricting drilling opportunities to those times when spraying was possible, some of the time advantage of no-tillage would have been lost.
2. It introduced yet another function to be observed by the operator and/or monitored, increasing the potential for error.
3. Some openers displace, or indeed throw, soil, causing dust, which inactivates

the most commonly used herbicides in no-tillage (glyphosate and paraquat). Spraying is better performed with a separate operation by a specialist prior to drilling.

Although blanket application of herbicides at the time of drilling appears to be impractical, banded application on each row has been used successfully (see Chapter 12).

Summary of No-tillage Drill and Planter Design – Large-scale Machines

1. Designs of no-tillage drills need to be more sophisticated than those of tillage drills.
2. No-tillage drills are invariably heavier than tillage drills and are more stressed during operation.
3. Wear and general maintenance are more important and expensive on no-tillage drills and planters than on tillage drills and planters.
4. The tractor engine power required to operate no-tillage drills and planters ranges from 3 to 9 kilowatts (4 to 12 horsepower) per opener.

5. The power requirements for no-tillage drills and planters are more sensitive to operating speed than those for tillage drills and planters.
6. Larger tractors are generally required for no-tillage drilling.
7. Because tractors are operated fewer hours per year than tillage tractors, their hourly operating costs are higher than the latter but their total annual costs are reduced.
8. The total energy expended per sown hectare and the annual operating cost of all equipment are much lower in no-tillage than for full tillage.
9. No-tillage drills are generally narrower than tillage drills because of the increased power requirement. No-tillage planters may be the same width as tillage planters because of fewer openers.
10. Although it is not as necessary to travel as fast during no-tillage drilling or planting as in tillage because of the time efficiency of the system as a whole, some no-tillage drills and planters are actually capable of higher speeds than their tillage counterparts. On the other hand, other no-tillage designs require low speeds.
11. Time analyses to cover a field with a relatively narrow no-tillage drill compared with a wider tillage drill often fail to account for the multiple tillage passes made before the tillage drill begins work.
12. Downforce systems on no-tillage drills and planters need to be more sophisticated, exert greater force and have a greater range of travel than for tillage machines.
13. The geometry of no-till opener drag-arm attachments must compensate for the increased drag forces.
14. Parallelogram drag arms with either gas or oil-over-gas hydraulic pressurized downforce systems provide the most consistent downforces and seeding depths.
15. Drill and planter frames should be suspended on wheel arrangements that minimize bounce from uneven ground.
16. Turning corners while drilling or planting is more difficult in no-tillage than in tillage because of the firmer soils.
17. The firmer ground in no-tillage is better able to withstand scuffing from the wheels when turning corners than with tilled soils.
18. Automated systems that return the opener downforces quickly to preselected values after raising the openers for transport are desirable in no-tillage because of the need to raise the openers more frequently during operation.
19. End-wheel drill and planter configurations are generally the cheapest option but have a maximum width of approximately 6 metres (20 feet).
20. Fore-and-aft wheel configurations allow greater drilling widths and simpler side-by-side joining of two or more drills or planters.
21. Delivery of product from hoppers to no-tillage openers is somewhat more demanding than for tillage drills because of the need for wide spacing between adjacent no-tillage openers to clear surface residues.
22. Because both tillage and no-tillage openers on planters are widely spaced, there are fewer special requirements for product delivery on no-tillage planters compared with drills.

14 No-tillage Drill and Planter Design – Small-scale Machines

Fatima Ribeiro, Scott E. Justice, Peter R. Hobbs and C. John Baker

Small-scale no-tillage farming is not only practical but may be the most important improvement to crop production and resource protection for developing nations to be advanced this century.

Characteristics

Small-scale no-tillage is usually characterized by small field sizes and limited availability of energy, often also accompanied by limited financial resources. Operation of large-scale tractor-drawn implements is neither practical nor possible for many farmers on small properties. For these reasons, most small-scale farmers use either hand-operating jabbing devices or drills and planters with one or two rows. Some triple-row planters are also available but are reasonably rare.

The limited number of rows influences several functions, including opener design. Some of these influences are beneficial. Others are not. For example, many of the more advanced opener designs discussed elsewhere in this book require up to 12 horsepower per opener, which is often beyond the resources of small farmers. Also, non-symmetrical openers, such as angled discs, are seldom regarded as an option on single-row machines because the side forces are

too difficult to counteract while keeping the machine heading in a straight line.

But small-scale no-tillage is benefited by the operator attention to each square metre being planted, and weeds and residues are often manipulated by hand or collected for heating fuel or animal bedding.

Another benefit is that most small-scale planters sow fertilizer and seed simultaneously in separate slots. In this way they may be considerably more sophisticated than many of their larger counterparts, some of which do not sow fertilizer at all under no-tillage because of the mechanical complexity of achieving such a desirable function with multiple rows spaced closely together.

Thus, while small-scale no-tillage might be disadvantaged in some respects by the necessary simplicity of drills, planters and available power, it may also benefit in other respects for the same reasons.

Range of Equipment

There is a wide range of small-scale no-tillage seeding equipment available, each suited to different sources of power and field conditions. The range includes hand jabbing, animal-drawn planters, power tillers and planters for limited-powered tractors. Despite the differences in power requirements, the

designers of most small machines recognize the need to be able to handle residues, open an appropriate slot, meter seed and perhaps fertilizer, distribute this to the opener(s), place it in the soil in an acceptable pattern, and cover and pack the seed and the fertilizer.

Hand-jab planters (dibblers)

Hand-jab planters are popular amongst small-scale farmers. Some form the primary means of sowing seeds under no-tillage. Others are kept in reserve for filling in spaces in crops otherwise sown with openers in rows. Since the residue-handling ability of small drills and planters is often limited, spaces occur if and when residue handling suffers along the row.

Hand jabbers may have either separate hoppers for seed and fertilizer or one hopper for seed only. Figure 14.1 illustrates a typical double-hopper jab planter.

A common seed metering device used on hand jabbers is a rectangular plate placed inside the hopper. When the handles are pulled apart, the seeds drop into the holes, which are delivered to the outlet and the discharge tube. Plates with different hole sizes are available according to the seed size. Seeding rates can be adjusted according to the number of holes in the seed plate that are exposed in the outlet.

Part of the attraction of hand-jab planters is that they do not require access to animal or tractor power and they are low-cost, light and easy to operate, although some skill is required (Ribeiro, 2004). For these reasons they are often used by women, which increases the available labour pool for small farmers, although no-tillage itself reduces labour demands significantly anyway.

By planting seeds in pockets, there is minimal soil disturbance so weed seed germination is minimized, resulting in easy hand hoeing between plants. The small size of the devices makes them suitable for operation on hilly, stony and stumpy areas and for intercropping (e.g. sowing mucuna between maize rows) and for planting in fallow areas.

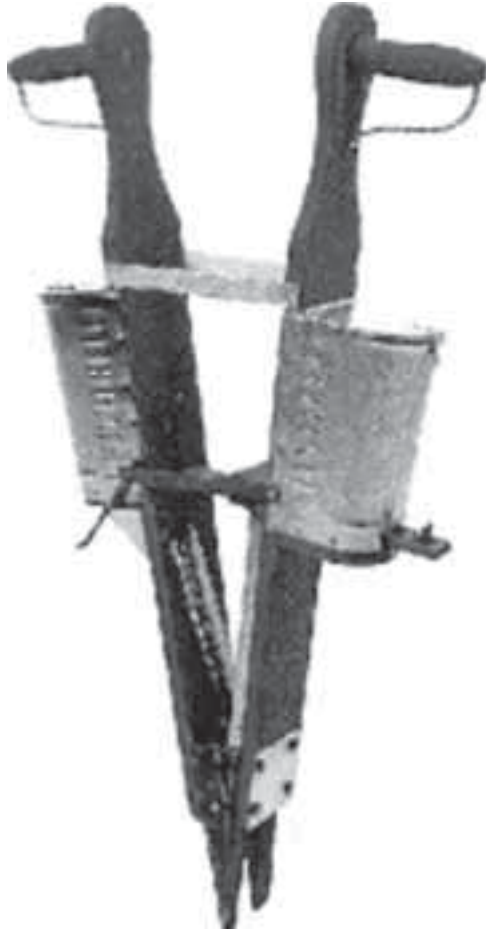


Fig. 14.1. A hand-jab planter with seed and fertilizer hoppers.

Their use is most suited to light soils since penetration is sometimes too difficult in harder soils in the absence of some form of tillage. Some clay soils may also stick to the blades when working in wet conditions and seed coverage may be affected by the V-shaped pockets and minimal disturbance (Ribeiro, 2004). This limitation is common to that experienced with V-shaped continuous slots and is not restricted to discrete pockets. But during the transitional phase from conventional tillage to no-tillage it may be difficult to use a hand-jab planter, in which case a ripper may be used to loosen a narrow strip where the hand-jab planter will place the seeds.

Many hand-jab planters for no-tillage are adaptations of similar devices designed for use in tilled soils. The main modification has been to provide longer and narrower points to improve penetration. Such improvements require less downward force from the operator and help to cut residues and penetrate the soil, resulting in less-open slots. They have resulted in 28% and 23.6% increases in emergence of maize and cowpeas seedlings, respectively, compared with shorter points operating in heavy residues (Almeida, 1993).

Row-type planters (animal-drawn and tractor-mounted)

The principles of operation of animal-drawn and tractor-mounted small no-tillage planters are the same as for larger machines. Some of these features are discussed below and comparisons drawn between small and large machines in terms of the conditions under which they each operate.

Downforce

With small machines, an opportunity exists to use weights as the method of downforce.

Springs are also used but hydraulic downforce systems are very rare. But weights have the same advantages as hydraulic systems at a much lower cost. In its simplest and cheapest form, weight can be applied by an operator standing on a platform on the machine. Figure 14.2 shows such a single-row machine directly mounted on a small tractor. The advantage is that the weight is easily applied and removed by simply stepping on and off the operator's platform.

Since weights apply a consistent downforce regardless of the vertical position of the opener, they act in a similar manner to oil-over-gas hydraulic systems applied to individual rams on each opener, which are a feature of some of the most advanced larger no-tillage drills.

Therefore, some small-scale no-tillage drills and planters may provide a more sophisticated downforce system than some of the less-advanced larger machines. The electronic modulation of downforce in response to ground hardness is not possible on the smaller machines. But, then again, nor is the direct application of weights a practical option for larger machines. Operators would need to be adding and removing multiple weights every time the downforce

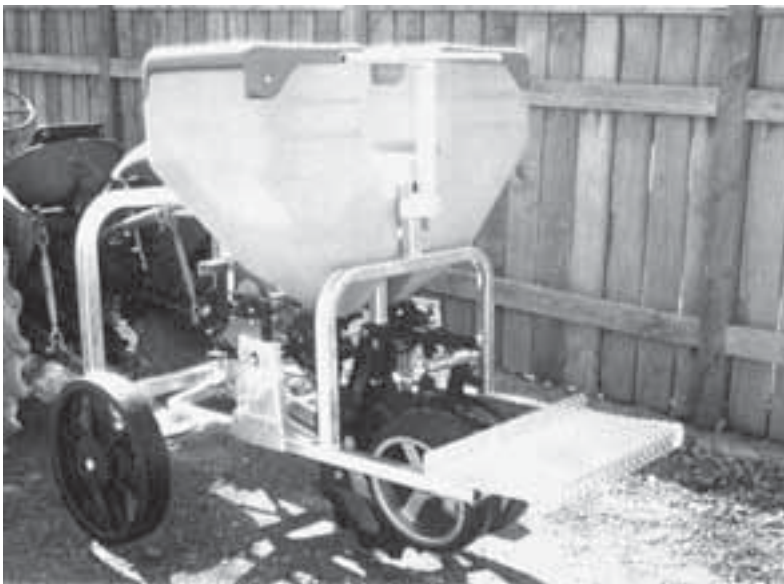


Fig. 14.2. A tractor-mounted single-row drill that relies on the weight of an operator for penetration.

was changed. Doing so might be acceptable on a single-row machine but would soon fall out of favour on a multi-row machine.

Figure 14.3 shows the main components of typical small-scale no-tillage planters. The disc (1) cuts straw (although the effectiveness of cutting straw in this manner often leaves much to be desired – see Chapter 10). Metering devices are positioned at the bases of the seed (2) and fertilizer (3) hoppers. The openers (4 and 5) open slots for placement of fertilizer and seed, respectively. Usually the fertilizer opener (4) operates deeper or off-line compared with the seed opener (5), in the same manner as bigger machines. The packing wheel (6) controls the depth of seeding and firms the soil over the slot. The effectiveness of packer wheels operating on the soil over the slot, compared with operating in the base of the slot before covering, is discussed in Chapter 6. In general, the value of packer wheels operating in the manner shown in Fig. 14.3 is more one of covering (which is important enough) than of improving seed-to-soil contact.

Discs

All of the principles of discs and residue handling, discussed in Chapter 10, apply equally to small-scale machines as they do to large-scale machines, except that with

single-row small-scale machines there is greater clearance around the opener for random residues to fall away without blocking the machine.

Most small-scale no-tillage planters have discs, the effectiveness of which are dependent upon the disc diameter and design (plain, notched, wavy, flat or dished), soil conditions, residue conditions and adjustments provided on the planter. Ineffective residue cutting results in clogging of straw on the seed components, which in turn results in problems for seed and fertilizer placement and coverage, and even seed and/or fertilizer metering.

Uneven straw results in hairpinning by discs and wrapping of residues on tined openers, although Casão and Yamaoka (1990) claimed that the severity of blockages could be reduced (though seldom eliminated) with increasing distance between the disc and any stationary tines that follow (they recommended a minimum distance of 25 mm).

On the other hand, some of the more successful combinations of tines and discs have the discs in close association with the tine. One example is shown in Fig. 14.4 (centre tine), in which a groove is created in the leading edge of the tine especially for the disc to operate within. Figure 4.27 shows the disc version of a winged opener in which two tines actually rub against the flat face of a disc.

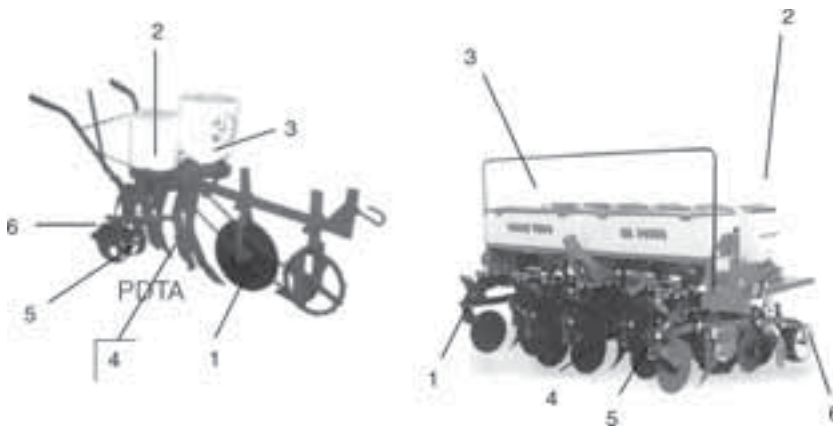


Fig. 14.3. The main components of typical small-scale animal-drawn and tractor-mounted no-tillage planters.

Openers

The functions of openers for small-scale no-tillage are no different than their functions for larger-scale machines and are discussed in detail in Chapters 4, 5, 6 and 7. On small-scale planters with tined openers, there should be independent adjustment of the fertilizer opener so that fertilizer can be placed deeper than the seed (Van Raij *et al.*, 1985). Although placing fertilizer beneath the seed in no-tillage does not always result in the best crop yield (see Chapter 9), with small-scale drills and planters it is a more realistic option than placing fertilizer alongside the seed because the latter option requires the fertilizer opener to be operating in new ground, which requires more energy than when both openers (seed and fertilizer) operate at different depths in a common slot. In any case, placed fertilizer within the seed zone is far superior to surface broadcasting causing slow crop access and increased weed growth.

As with larger machines, there are advantages for slots with minimal disturbance (see Chapters 5, 10 and 13). While the choice of opener type might depend on soil resistance to penetration and the amount and resistance to cutting of residues, it is no more feasible for small-scale no-tillage farmers to possess more than one no-tillage machine in order to cope with varying conditions than is the case for large-scale farmers.

Therefore, to be universally useful for practising farmers (large or small), it is inevitable that the choice of preferred opener types will, over time, gravitate towards those that function best in the widest possible range of conditions. Tillage has as one objective to reduce the physical variability between different soils so that drills do not have to cope with widely varying conditions. But, when the tillage process is eliminated altogether, emphasis then shifts to the capability of no-tillage openers to cope unaided with this variability. By definition, this demands increasing sophistication from the designers of no-tillage openers, regardless of their scale of operation.

Double disc openers (V-shaped slots with Class I cover) are commonly used on

small-scale drills and planters. The slots are narrow at the surface and may be compacted at their bases and sides, but are less power-demanding than tine-disc openers that have less compacting tendencies. With unequal-diameter double disc openers, because the smaller disc rotates faster than the larger disc a degree of cutting, or 'guillotine' effect is created (Fig. 4.3 – Chapter 4).

A range of tined openers is shown in Fig. 14.4. Generally, tines require less down-force than double disc openers, which contributes to maintaining a uniform seeding depth if a suitable depth-control mechanism is included. Tines are preferred in hard soils, although their drag force may become excessive for the power available. And tines are more susceptible to blockage with residues and are unsuitable in stony areas.

None the less, most of the planters used in small-scale agriculture have tines because of their better penetration of hard ground and ease of manufacture. In situations where



Fig. 14.4. A range of tined openers used with animal-drawn no-tillage planters. The centre opener has a groove cut into its leading edge, in which the leading disc rotates.

soil crusting is a problem (such as where cattle have trampled the soil when wet), only tractor-mounted planters with tined openers will break the compaction in the soil surface, although this is often only 100 mm deep.

Seed metering devices

There continues to be debate amongst researchers about the importance of seed spacing along the row with row crops such as maize (Sangoi, 1990; Rizzardi *et al.*, 1994). More recent evidence has shown that uniform plant emergence along the row may be more important than plant spacing to reduce plant competition of smaller plants by larger plants. But the fact remains that, if 'perfect spacing' has become the accepted norm in conventionally tilled seedbeds, no-tillage exponents need to match this norm in untilled seedbeds in order to avoid introducing an unnecessary negative factor against no-tillage.

Seed metering devices are responsible for governing seed rate (number of seeds/m) and seed spacing (consistency of spacing between seeds in the row); thus their accuracy must be assured.

Most crops sown by small farmers are in wide rows. Singulation of seeds is therefore important. So emphasis is placed on seeding mechanisms and power requirements as priority design criteria. This contrasts with larger no-tillage planters where slot micro-environment, residue management

and fertilizer banding assume at least equal importance to seed spacing and energy requirements.

No-tillage farming in Brazil provides an interesting comparison and contrast of small-scale machines and tractor-drawn machines. Both systems are practised widely in a country that spans many climatic and socio-economic zones, often in relatively close proximity to one another.

Seed metering devices used on animal-drawn no-tillage planters in Brazil all feature the same gravity seed plates that are used on local tractor-mounted planters, namely plastic or cast-iron horizontal plates. Figure 14.5 illustrates a horizontal plate-type metering device along with several alternative plates. Some manufacturers provide seed plates suited to small seeds (e.g. canola, hairy vetch, forage radish) as well as maize and other larger seeds.

The use of such devices has been driven by their relatively low cost, since most singulating seeders used in countries that do not have small-scale agriculture are now of the vacuum, air pressure or 'finger-picker' type, which involves seeds being sucked, blown or clamped against vertical plates rather than falling under gravity into holes or notches in horizontal plates. Vertical plate seeding mechanisms are faster and less sensitive to seed shape and size than horizontal plate-type seeders, but are also more expensive. Of course, vacuum and air singulators also require a powered air fan as the basis of operation and this would be



Fig. 14.5. A horizontal plate metering device (left) used in precision planters, with an array of optional seed plates (right).

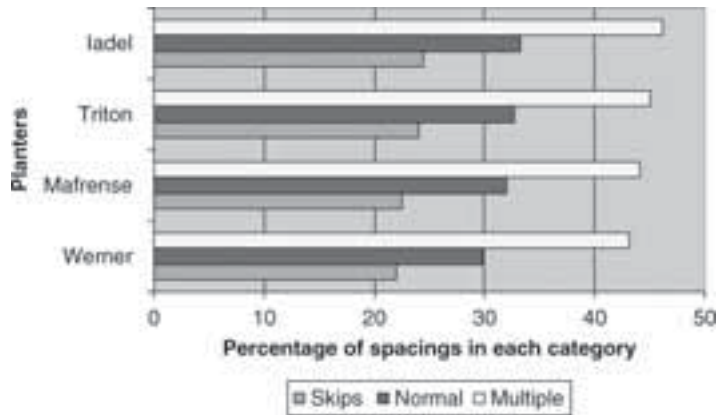


Fig. 14.6. Percentage of normal spacings, skips and multiple seeds provided by four models of animal-drawn no-tillage (NT) planters (Ribeiro *et al.*, 1998). The criteria for classification of spacing is based on Kurachi *et al.* (1993). Each crop has an ideal spacing (X_{ref}), which depends upon the recommended number of plants/m. For example, if for maize the recommendation is 7 seeds/m, then X_{ref} is $1.00/6 = 0.17$ m. In this manner the following classes are established: normal ($X_{ref} < X_i < 1.5 X_{ref}$); doubles ($X_i > 1.5 X_{ref}$) and skips ($X_i < 0.5 X_{ref}$).

difficult to facilitate on an animal-drawn machine without resorting to a stationary engine.

Horizontal plate singulators are a very old, well-proven and refined system that pre-dated the vertical plate systems now in common use on larger planters. It is no surprise, therefore, that, when Ribeiro (2004) evaluated the uniformity of distribution of maize seed along the row with four models of plate planters in Brazil, she found no significant differences between models in the proportion of normal spacings, skips and doubles. The results are summarized in Fig. 14.6.

To be most effective, horizontal plate singulators require the seed to be graded into uniform sizes and the holes or cups in the plates to be matched to the chosen seed size. This requires having several plate sizes and some experimentation when seed lines or batches are changed. But, with limited numbers of rows and small quantities of seed, this is not a difficult undertaking compared with multi-row machines. But it does highlight the importance of being able to change plates without emptying the entire seed hopper. Figure 14.7 illustrates a closed hopper system that allows the plate to be changed without spillage of seed.



Fig. 14.7. A closed hopper system for easy seed plate change.

Fertilizer metering devices

The types of fertilizer metering devices found on small-scale no-tillage machines

include rotating bottom, auger type, edge cell and star wheels (Figure 14.8). The discharge rate for star-wheel and rotating-bottom types is controlled by adjustable outlets, while auger and edge-cell types are controlled by changing their speed of rotation relative to the ground speed (Ribeiro *et al.*, 1998).

Packing wheels

While seed row packing wheels vary in design, most are of either steel or plastic construction. V-shaped wheels are used where soil disturbed by tined openers needs to be collected and thrown into the open slots. Good coverage/compaction depends on the depth of seed placement, the type of seed compaction wheel and soil moisture. Open-centred wheels are better for soils with a tendency towards crusting as they press the soil laterally towards the seed.

Power requirements and ease of operation

Small-planter operation requires more intimate operator involvement than for larger machines. Therefore ease of operation is important. For example, most small planters require the operator to hold a pair of handles and steer the machine, as well as controlling the animals that may be pulling them. With small tractor-drawn machines, a second operator usually controls the tractor. In either case, energy requirements are important. But, since the openers used on most small planters are similar to those

used on larger machines, all of the forces and principles of soil reaction apply equally to both classes of machine.

Of the seven machines reviewed by Ribeiro *et al.* (1998), four featured tined seed openers and three featured double disc openers. Ralisch *et al.* (1998) evaluated the draught and energy requirements of a small planter with tined seed and fertilizer openers in an untilled soil of quite low bulk density, 1.07 g/cm^3 , operating at 100 mm depth. They recorded a draught force of 834 N, which is less than half the values recorded by Baker (1976a) for a single simple winged opener (see Chapter 13).

Draught forces vary widely with soil strength, which is itself influenced by soil moisture content, soil type, SOM and the time under no-tillage. So it is difficult to compare opener (or, indeed, drill) types in different conditions. But, at 2.4 km/h, the machine tested by Ralisch *et al.* (1998) would require 1.4 kW of draught power or approximately 3.6 kW (5 hp) of tractor engine power (at a tractive efficiency of 0.65). This compares with larger drills, which commonly require 4–9 kW (5–12 hp) of engine power per opener to operate at up to 16 km/h. Such high forward speeds are unobtainable by small machines, even if sufficient power is available, because of the difficulty in controlling them at high speed, especially if the operator walks behind the machine. Therefore the lower power requirement for small machines probably reflects the lower operating speeds more than other variables.

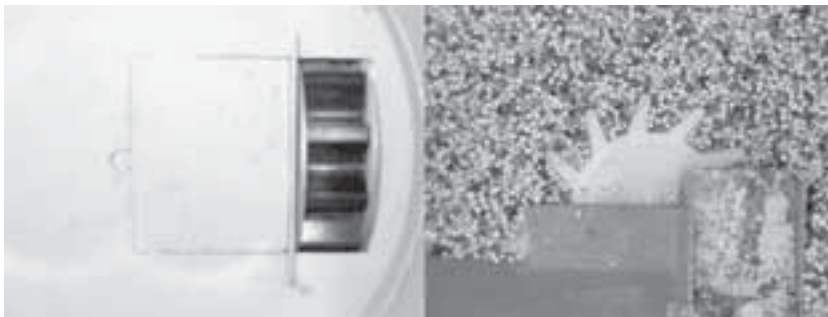


Fig. 14.8. Two examples of fertilizer metering devices used on small-scale no-tillage planters. Left: edge cell (or fluted roller); right: star wheel.

According to Siqueira and Casão (2004), differences in power requirements are primarily due to the design of the openers, the weight of the planter and the number, and the contact surface area of the residue-cutting and groove-opening components. The main characteristic that makes such machines suitable for small tractors or animals is the small number of rows: two and three rows for maize and soybean planters and six to seven rows for wheat and rice drills.

Some of the factors that contribute to the physical effort by the operator in controlling the machine are the weight of the planter, the height of the handle(s), manoeuvrability, stability and ability to operate on sloping ground. The height of the handle(s) becomes particularly important during headland manoeuvres and in most cases is adjustable. Multiple-row models generally require less manual effort from the operator than single-row models, because seats or standing platforms are provided.

Models with two rear support wheels provide good stability when working on flat land but may be constrained on hillsides. Models with only one wheel are more adapted to stony and stumpy areas because it is easier to steer such machines around obstacles. For those models that evolved from 'fuçador' ploughs, improved stability occurs when fixed-shaft systems are used rather than chains. The 'fuçador' plough consists of a wooden drawbar, which is fastened to the yoke of the draught animal(s), on which is mounted a leg and a shovel-like plough body (Schimitz *et al.*, 1991). For no-tillage, the mouldboard plough body is replaced with no-tillage openers. The device is used in the stony and hilly areas of south Brazil.

Adjustment and maintenance

All models offer adjustments of both seed and fertilizer sowing rates. But some models do not offer many adjustments either for seed and fertilizer sowing depth or for residue handling. On the other hand, the most sophisticated openers do not require adjustments to handle a wide range of residue

types, but these are seldom used on small drills or planters. In general, tined openers have the poorest residue handling characteristics (see Chapter 10) and disc openers the best. But certain disc openers (e.g. double disc) have a tendency to hairpin pliable straw into the slot, where it interferes with seed germination in both wet and dry soils. These disadvantages apply equally to small planters as to larger equipment.

For this reason, several small planters with tined openers provide adjustments that affect their residue-cutting ability. The two main adjustments are the hitching point and the front ground wheel. Adjustments made to the disc will also affect the depth of the fertilizer slot. For the same depth of the fertilizer, different depths for seeds are possible through adjustments of the rear ground wheel.

In the simplest models, seed rates are adjusted by changing to different seed plates, while multiple-row models often provide sets of gears to change the plate speed. Other models that do not sow widely spaced rows provide geared adjustment of the speed of bulk seeders.

Animal-drawn planters

Figure 14.9 shows a range of no-tillage drills developed in Brazil. The models shown in the two top photographs are more sophisticated, have a greater range of adjustments and are likely to produce better results than the models shown in the two middle photographs, which have evolved from 'fuçador' ploughs. They are lighter, less expensive and more adaptable to hilly and stony areas. The model shown in the bottom photograph features disc openers and platforms for an operator.

Planters adapted from power tillers

Power tillers that are normally used for conventional tillage are sometimes used for strip tillage by eliminating some of the powered blades to till narrow strips (20 to 200 mm wide), leaving the ground between



Fig. 14.9. A range of small-scale no-tillage planters developed in Brazil.

the rows (up to 500 mm wide) untilled. Chapter 4 addresses the issues of how larger versions of such machines have been adapted to follow the ground surface and Fig. 4.22 shows an example of one such machine producing narrow strips.

Tractor-drawn planters

Small farmers also use animal-drawn or small tractor planters requiring up to 50 hp. The machines have the same straw-cutting (smooth disc) and slot-forming (tine or double disc) openers as the single-row machines

and most are capable of applying fertilizer at seeding time.

Some models provide bulk seed and/or fertilizer hoppers in a similar manner to larger machines (e.g. Figs 14.10 and 14.11) while other models are set up as multi-row precision seeders (e.g. Fig. 14.12).

No-tillage farming in Asia

Zero-tillage (or no-tillage) has been adopted on about 10–15% (2 million out of 13.5 millions hectares) of the wheat planted after rice in the rice–wheat cropping system in India and Pakistan. Spring wheat planted in



Fig. 14.10. A small tractor-drawn no-tillage drill.



Fig. 14.11. Two small planters with bulk fertilizer hoppers and precision seeders.

the winter season and, increasingly, other winter crops, such as lentils, are being zero-tilled. Yet the gains in soil health from the winter season are countered by puddling of summer rice. In addition, the vast majority of the zero-tillage occurs in fields where the rice residue either is removed as fodder or fuel or is burned, because the current low-cost zero-tillage drills have no residue-handling capacity. In many cases, only anchored straw remains. This leads to a hybrid system where yields cannot and will not be maintained due to soil degradation.

Long-term experiments in Mexico have shown that zero-tillage without residue

retention in intensive maize–wheat systems results in more rapid decline of yields than where a full tillage system is retained in which residues are buried. But the best treatment has been no-tillage with residue retention (Govaerts *et al.*, 2004). This points out the need for ‘rational residue retention’ in the humid tropics and subtropics with heavy monsoons and sometimes triple-crop annual intensity (K. Sayre, 2004, personal communication).

There is currently research being initiated and undertaken in some parts of South Asia on direct-seeded or zero-tilled rice (RWC website). There is little or no



Fig. 14.12. A small planter adapted from animal operation for tractor mounting.

prior research on how to plant zero-tilled rice under monsoon conditions. The major problems facing scientists and farmers are: (i) planting time decisions influenced by erratic onset of pre-monsoon and regular monsoon rain and little or no assured irrigation schedule that can otherwise keep machinery from entering fields when they are too wet; (ii) the enormous weed management problems brought about by the loss of puddle conditions in sandy soils that allow fast infiltration and therefore reduce the ability to control weeds by impounded water; and (iii) the lack of drainage, especially in the lowlands, which can submerge and kill recently emerged seedlings. Current experiments include zero-tillage of transplanted rice, newly available herbicides, rice varieties that can withstand submergence and varieties that do well in alternating flooded and dry conditions.

Table 14.1 summarizes the special problems for zero-tilled rice.

Research into residue retention is progressing, but the normal Western technologies, such as double disc openers, are probably too expensive, heavy and need excessive power. Indigenous or locally made systems, such as openers, with inverted-T,

double disc and star-wheel injector planters are moving forward. But research suggests that much cheaper strip-tillage systems might provide the answer to low-cost handling of residues, especially for wealthier farmers. For poorer farmers, residues are highly valued for fuel and fodder and will probably remain so for several decades.

Two-wheeled or four-wheeled tractors?

It is a problem to learn how to apply conservation agriculture methodologies in the intensely poverty-stricken areas of South Asia. Although zero-tillage drills are becoming more available, there is a dearth of four-wheel tractors. As a result of poverty, many holdings are small and scattered. Intense monsoon rains provide large challenges to researchers, conservation agriculture proponents and machinery designers. Whichever system(s) become dominant, it is likely that the majority of small and poor farmers will not own their own equipment but will rent from service providers.

There have been efforts in recent years to bring conservation agriculture to two-wheeled tractor farmers. Although the area

Table 14.1. Problems and possible solutions for zero-tilled rice.

Problems	Possible solutions
1. Majority of rice is rain-fed. Major problems are erratic monsoon and therefore problems of entering fields for seeding operations.	<ol style="list-style-type: none"> 1. Planting needs to be done as quickly as possible when the proper soil moisture is reached. Once the field is too wet serious compaction will occur. 2. Smaller, lighter machinery (two- and four-wheel tractors) may help. 3. Farmers may want to have the option of transplanting by hand or machine into zero-till fields if direct seeding is impossible. 4. Move to early dry-season irrigated rice.
2. Lack of drainage and flooding kills off emerging seedlings after a heavy downpour of monsoon rain.	<ol style="list-style-type: none"> 1. Permanent beds and introduction of some drainage capability. 2. Flood-tolerant rice varieties are also possible. 3. Transplanted zero-tilled rice.
3. Problems of weed control when soils are not kept flooded (more serious on research stations than in farmer fields).	<ol style="list-style-type: none"> 1. Integrated weed management will be the key, using competitive varieties, mulching, preventing seed set of weeds, rotation and various herbicide strategies. Untilled seedbeds where the first flush of weeds are allowed to germinate and then controlled with herbicide is another strategy. In this system, avoiding ploughing will avoid a new flush of weeds germinating. 2. Planting of a cover crop after wheat and killing the cover crop and weeds with herbicide before zero-tilling rice.

of adoption is still small, engineers and researchers feel they are finding attachments to fit into this complicated socio-ecological system.

Four-wheeled tractors

India is the largest tractor manufacturer in the world in terms of numbers. Still today, only 50% of tillage is mechanized in India (perhaps 90% in the rice-wheat areas) and less than 20% in Nepal, but greater than 70% in Bangladesh. The surprising gap between Bangladesh and the rest of South Asia is discussed later. Further, the Indian government laws prohibit tractor manufacturers from manufacturing implements such as seed drills in order to promote local small manufacturing.

TOOLBARS AND TOOLS. Many machine toolbars in India and Pakistan are based on

early 'rabi' (winter wheat, lentil) seed drills that were developed in the 1970s and 1980s. The manufactures of conservation agriculture machinery have for the most part simply strengthened the frames, bars and shanks (Hobbs and Gupta, 2004). The toolbars are flat (i.e. not diamond) and generally made from two pieces of 50 mm angle steel welded together to form a square toolbar. Two or three bars are positioned at fixed distances. There are various systems for attaching the shanks to the toolbars. Farmers are learning that an adjustable shank length provides more adaptability but has a tendency to swing to one side or another if not properly tightened or if of inferior quality.

ZERO-TILLAGE DRILLS. The current level of enthusiasm for conservation agriculture research and development in South Asia was sparked by a CIMMYT (International

Centre for the Improvement of Maize and Wheat, Mexico) programme that imported simple inverted-T drills from New Zealand (Baker, 1976a, b, Fig. 14.13) into Pakistan in the early 1980s for wheat. Over a period of time, various national and international programmes in Pakistan and India reduced the size and cost of the initial machines and 'indigenized' them. Specifically, the popular locally made 'rabi' or winter wheat drills were strengthened and locally made inverted-T openers attached (Hobbs and Gupta, 2004).

Toolbar platforms and tools for zero-tillage have become as uncomplicated and light as possible (Fig. 14.14). Nearly any medium-sized workshop is able to produce them. The first system to fail on locally made tractors is the draught control system and the second is the hydraulic lift. Many farmers who purchase zero-tillage machines therefore find that their three-point-hitch hydraulic lifts soon need overhauling. So most zero-tillage drills come with various types of depth-control wheels. In Pakistan, pneumatic tyres are often used, but the

cheaper Indian and Pakistani models have metal wheels.

STRIP TILLAGE DRILLS. Much less popular than either zero-tillage or bed planting are strip tillage drills for four-wheeled tractors (Fig. 14.15). These drills were developed by Indian scientists and engineers at Punjab Agricultural University, Ludhiana, in the late 1980s. Typically they comprise a simple 2.2 metre PTO driven 'rotavator' with four blades or six blades per strip and they come in nine to 11 row models. Such machines cost 50% more than zero-tillage drills. Fuel consumption is greater than zero-tillage but much less than conventional tillage. Farmers remark that strip tillage helps in fields where residue levels are too high for the simple inverted-T zero-tillage shanks. Yields are comparable to those of zero-tillage (Hobbs and Gupta, 2003). Pakistan research on rotating discs, smooth and serrated, reported that the disc wear was high.

STAR-WHEEL (PUNCH) PLANTERS. In an attempt to solve the problem of planting into



Fig. 14.13. Inverted-T openers mounted on rigid shanks attached to a square hollow toolbar. (Note that details of typical inverted-T openers can be seen in Figs 4.22, 4.23 and 4.24 – Chapter 4.)



Fig. 14.14. A typical zero-tillage drill on a typical Indian tractor.



Fig. 14.15. Strip tillage drill from India.

heavy residue, star-wheel or rolling punch planters (originally developed in Zimbabwe) have been added to existing zero-tillage frames (Fig. 14.16). Modifications

have been made to assist with synchronization of seed delivery and to prevent seed from falling outside the punch (RWC website). Perhaps the biggest problem facing



Fig. 14.16. A multi-row rolling punch planter.

this system in South Asia is its relatively high cost.

BED PLANTERS (RIDGE AND FURROW PLANTING). Bed systems for wheat were originally developed by Mexico's Yaqui Valley farmers to compensate for dwindling water supplies. Irrigation water is saved by applying it through the furrows between the beds, which greatly enhances water conservation and drainage. Bed-planted wheat also allows access to the field after planting for chemical applications and mechanical weeding. More than 90% of Yaqui Valley farmers have now adopted the practice (Aquino, 1998), but they still completely knock down the beds and reshape them for the next crop.

Work began on bed-planted wheat in South Asia in the mid-1990s and current adoption is increasing (Hobbs and Gupta, 2004). The goal is to eventually have permanent beds, especially on the dry sandy soils, where groundwater supplies are fast receding, or on clayey soils, where wheat is prone to waterlogging. Some variations exist for adapting to the erratic monsoon problems and low-yielding direct-seeded rice by transplanting rice by hand on to beds using inverted-T openers to open the slots for transplanting. There might be good prospects for bed-planting of rice-vegetable rotations in India or cotton-wheat rotations in Pakistan.

Work is still needed to successfully grow dry-seeded rice on beds, including selecting sowing dates, weed management, soil types and climatic and socio-economic situations under which permanent beds will be of benefit. There are still questions to be answered about the shift from anaerobic to aerobic fluctuating conditions for rice. And there are questions about the most appropriate machinery to be used, since the more complex monsoon systems of Asia might require more adaptation of designs first created in the Yaqui Valley (Mexico) ecosystem (Sayre and Hobbs, 2004).

The majority of current commercial bed-planter designs are derivatives of zero-tillage drills, using the same frames and fluted roller seed meters, but with simple adjustable-width furrower shovels added. Much work has been undertaken on the agronomy of wheat and rice and two rows sown on 72.5 cm beds has become the standard in rice-wheat rotations, although most planters can be adjusted to three rows and varying bed spacings. Some designs offer zero-tillage bed-planter combination machines that have extra inverted-T openers, shovels and shapers. But these designs seem to be inadequate for permanent beds and increased residue levels, and work has started on adding double disc openers and star-wheel punch planters.

'HAPPY SEEDER'. The 'happy seeder' (Fig. 14.17) was designed to handle high rates of residue and seed either on beds or on the flat. The drill is a combination of two machines, a forage harvester and a zero-tillage drill using inverted-T winged openers (RWC website). The forage harvester cuts, chops and lifts the straw, providing the drill with a clean surface for zero-tillage drilling. The chopped material is blown directly behind the drill and floats down as mulch. Field trials in India have confirmed the usefulness of the approach. But problems with germination and skips have persisted and resulted in the need for adjustment for the cutting height as well as strip tilling in front of each inverted-T opener. Adaptations in Pakistan have resulted in optional separation of the two halves of the machine.



Fig. 14.17. An example of a 'happy seeder'.

Two-wheeled tractors

Relative poverty results in landholdings becoming smaller and more fragmented. A successful small farmer might own 5 hectares while a financially poor small farmer will own less than a hectare with an average of five fragmented parcels. The number of four-wheeled tractors declines to virtually zero for poor farmers, as does other modern machinery. The eastern India and Bangladesh areas (Fig. 14.18) have arguably the most fertile land in all of South Asia; yet poverty and very high population density offer conservation agriculture researchers a particular difficult and restrictive socio-economic situation.



Fig. 14.18. The South Asian 'poverty square', where 500 million farm-supported families each live on less than 1 hectare of land per farm.

If conservation agriculture is to be introduced and adopted by farmers of this region, the equipment must be adapted to either bullock or two-wheel tractor power sources. These power sources must also be made widely available, as there are currently large areas where even the simplest power sources are not available. Two-wheeled tractors have been seen as appropriate and socially equitable (Justice and Biggs, 2004a), since the cost of keeping a pair of bullocks for land preparation and some transport are becoming prohibitively expensive. Many farmers seek alternatives to animal-drawn options, but developers here and perhaps in other underdeveloped regions face many extra hurdles:

1. The inherent conservative nature of all farmers, but particularly those who are resource-poor and can ill afford to take cropping risks.
2. A substandard infrastructure, including local manufacturers and extension systems, together with low literacy, slows interest in or adoption of any technology.
3. All farmers focus on low-cost machinery investment and forgo quality for price.
4. The limited research and development on conservation agriculture attachments for two-wheeled tractors compared with four-wheeled models.
5. Emphasis on four-wheeled tractors and indigenous production has limited the availability and competitiveness of two-wheeled models.

THE ROLE OF TRANSITIONAL TECHNOLOGIES.

Despite these hurdles, sales of two-wheeled tractors and the common 'rotovator' have increased in the last decade, especially in Bangladesh, where it is estimated that more than 400,000 Chinese-made two-wheeled tractors undertake more than 70% of land preparation by Bangladeshi farmers. This dramatic increase was brought about by changes in government policy and development of a vibrant market for tractors following a severe cyclone disaster and floods in 1987 that decimated the animal population. A similar picture is emerging in Nepal and to some extent in India. Special

projects in Nepal have made farmers more aware of the benefits of owning such power sources to generate income or to provide contractor services for non-owners of tractors (Justice and Biggs, 2004b). The availability of such power sources now allows conservation agriculture methods and techniques to be made available to farmers in these regions.

Besides providing power for conservation agriculture, these tractors undertake a multitude of other activities, such as reaping, pumping, seeding and tillage. The tractor, or its engine, is also used as a power source for threshers, winnowing fans, milling and transport for people and goods, both on land (pulling 2 t trailers) and on water (thousands of country boats in Bangladesh). They also reduce the drudgery of puddling rice paddies when cage wheels are fitted. All these functions speed up farm operations (timely land preparation, sowing and harvesting), improve yields and increase cropping intensity and efficiency of crop production. These results are all vital for an area where population densities exceed 1000 people per square arable kilometre.

Land preparation costs for both winter crops and summer puddling of rice are one-third less per unit of land with two-wheeled tractors than with four-wheeled tractors (Sah *et al.*, 2004). The time spent by four-wheeled tractors in turning and backing is also eliminated with two-wheeled tractors, especially in small fields. The challenge has been to extend these advantages to conservation agriculture. First, a toolbar concept has been used in zero-till and bed planters; and, secondly, a reduced-till/shallow-till seed drill has been modified to strip-till and form beds in one operation.

TOOLBARS. As with four-wheeled tractors, toolbar designs for two-wheeled tractors are largely based on modifications of the familiar 'rabi' flat-bar seed drills. The mounting plate for the toolbar is bolted to the rear of the transmission of two-wheeled tractors. Such a rigid mounting system in uneven fields is a problem compared with more flexible three-point-hitch systems. None the

less, it has proved to be a robust platform for conservation agriculture implements. Generally, two bars are used to attach tools and implements.

TOOLBAR ZERO-TILLAGE DRILLS. Most two-wheeled tractors are capable of pulling up to four-row zero-tillage seeders. Designers have simply adapted the designs of the four-wheeled tractor zero-tillage drills to the reduced row numbers, using full-sized inverted-T openers and the same shanks but having downsized the seed and fertilizer hoppers (Fig. 14.19). The effective field capacity of such machines is typically 0.20 ha/h for simultaneous seeding and fertilizer application. Planting cost for wheat and maize has been reduced by some 50% compared with conventional tillage methods.

TOOLBAR BED PLANTERS. Bed planters that simultaneously till the soil and form the bed are not considered, regardless of whether or not they also sow seed and fertilizer, although such a practice may eventually lead to a full no-tillage programme involving permanent beds.

Bed width is limited mainly by limitations on wheel spacing of two-wheeled tractors. The standard rice-wheat bed is 65–70 cm wide. Problems occur when first forming beds if the land is not previously prepared. The shovels grab at clods, pulling the machine off course, which may cause handling problems if one wheel travels into a



Fig. 14.19. A zero-tillage flat-type toolbar showing the mounting plate for a two-wheeled tractor.

furrow and tilts the bed former. Clods are less of a problem under permanent bed conditions where light reshaping of the bed is performed and the wheels track nicely in the furrows and greatly reduce fatigue of the operator.

REDUCED-TILLAGE SEED DRILL. A Chinese-designed reduced-tillage/single-pass seed drill was introduced into Nepal in 1989 and Bangladesh in 1996 by CIMMYT. It has been the only conservation technology available from China for two-wheeled tractors in those regions and has undergone much research by Pradhan *et al.* (1997), Meisner *et al.* (2003) and Sah *et al.* (2004), who demonstrated consistently high yields for the following reasons:

1. It was able to drill wheat, lentils and other winter crops into very wet soils (up to 30% moisture content) immediately following the rice harvest, avoiding late planting.
2. It provided a very fine soil tilth, which ensures germination.
3. It placed seeds at a uniform depth.
4. It reduced weed problems associated with the previous rice crop.

Although the machine cannot be considered a true no-tillage drill when in its full-tillage mode (Fig. 14.20), it represents an excellent transitional (and flexible) technology from multiple ploughing to zero- or strip-tillage (Fig. 14.21). The drill's three main components are:

1. A 48-blade, 120 cm wide high-speed shallow tillage (maximum 10 cm deep) 'rotovator'.
2. A six-row fluted roller seed meter (11 and 17 flutes available) and seed bin.
3. A 120 cm roller for planking, compaction and depth control.

STRIP TILLAGE. Research on strip tillage is more recent (Justice *et al.*, 2004), but results have been promising using the Chinese-designed machine. Field efficiency improves by 15–20% with less fuel and time consumption. The soil area disturbed can be adjusted from 15 cm to as little as 2–3 cm (with straightened blades). For narrow



Fig. 14.20. A two-wheeled reduced-tillage machine in full-width tillage mode.



Fig. 14.21. A two-wheeled reduced-tillage machine in strip-tillage mode.

stripping, additional blade holders are welded to the axle to compensate for the absence of a normal spiral pattern and to reduce vibrations. Work in Mexico,

Bangladesh and Nepal has shown that this system's high-speed 'rotovator' blades (which rotate at greater than 400 rpm) are able to cut and seed into loose straw and may

present an inexpensive machinery solution for the residue retention problems throughout this region for two- and four-wheeled tractors. Figure 14.21 shows a self-propelled two-wheeled strip tillage machine creating 50% disturbance and sowing wheat in 100 mm spaced rows.

PERMANENT CONSERVATION AGRICULTURE BEDS. The flexibility of the Chinese-designed drill has recently been extended to making new beds and seeding in permanent beds with very few modifications. When it is necessary to reshape permanent beds, the toolbar system with shovels can be used, or only a few rotary blades in the furrow might move soil back on to the undisturbed bed.

STRIP TILLAGE ON PERMANENT BEDS. If the beds do not require reshaping, the same machine simply strip-tills on the existing beds. In Mexico and Bangladesh, modifications to conventional strip tillage machines have been carried out by CIMMYT as follows:

1. Two depth-control wheels are positioned in the furrows in place of the roller.
2. The furrow openers are extended down about 7 cm.
3. The standard 'C'-type blades are straightened to cut through residue and reduce the amount of soil movement.
4. Extra blades are added to reduce vibration (circled in Fig. 14.22).

Figure 14.22 shows a modified strip tillage machine/seed drill, in this case used for drilling mung bean after wheat on permanent

beds. The straightened 'C'-type blades (inset) are able to cut the residue, leaving it on the surface of the bed with minimal soil disturbance or raking, which is otherwise found with fixed inverted-T openers.

There has been much debate about the most desirable height for beds of this type. Most bed planters can only make beds up to 10–12 cm high. Early attempts to create higher beds are now recognized as wasting energy and are often agronomically undesirable as they dry out more quickly. It is now generally accepted that beds need only to be as high as is necessary to allow water to move from one end of the field to the other for irrigation or to drain the field. Because many fields are small (average less than 0.2 ha), lower beds are sufficient.

Strip tillage systems based on two-wheeled tractors also involve comparatively lightweight machines that allow seeding into wetter soils compared with four-wheeled tractors and their associated bed planters. This is important in conservation agriculture systems in South Asia with both flat and low-bedded applications.

On the negative side, two-wheeled strip tillage on permanent beds does not allow access back into the field after the crops are established. It would be desirable to facilitate banded top dressing, inter-row cultivation and spraying as with four-wheeled tractor models.

Results of recent tests with wheat establishment in Bangladesh (Rawson, 2004) found full tillage and strip tillage to be initially superior to bed planting and

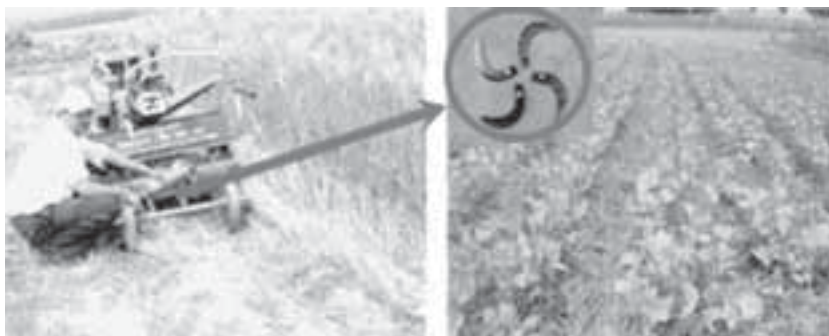


Fig. 14.22. A strip tillage drill operating in heavy residues on a permanent bed, sowing mungbean.

zero-tillage, but also noted that results improved after operators had learned to plant at the correct soil moisture content, especially with no-tillage. As a result, it is now believed that bed-planting and no-tillage with two-wheeled tractors may be the future of conservation agriculture in that region.

Summary of No-tillage Drill and Planter Design – Small-scale Machines

1. Most small-scale farmers use either hand-operated jabbing devices or drills and planters with one or two rows pulled by animal or small tractor power.
2. Small-scale no-tillage farming benefits from increased operator attention to seeding and weeding details.
3. Many designs of hand or animal planters have evolved from simple ancient designs.
4. Small-scale opener designs have many of the same requirements and designs used on larger-scale farming presented in previous chapters.
5. Some small-scale opener designs are restricted by power, downforce and symmetry requirements.
6. Providing separate fertilizer and seed placement at seeding time is important to enhance early crop availability and reduced weed growth.
7. Seed and fertilizer metering devices most commonly resemble adaptations of those used in larger machines.
8. Hoe openers are more common in small-scale farming due to increased penetration capability compared with disc openers.
9. Residue handling is often easier with small-scale machines as a result of fewer rows and openers.
10. No-tillage in Asia presents special problems associated with rice–wheat rotations and monsoonal rains.
11. Extreme poverty is a further problem in areas of Asia, which limits the sophistication of no-tillage equipment and consulting services to service farmers.
12. Widespread use of simple winged (inverted-T) openers has opened opportunities for no-tillage in Asia.
13. Bed planting and/or strip tillage is seen as an interim step towards full no-tillage in Asia.
14. ‘Happy seeders’, which combine forage harvesters and seeders, allow residues to be placed over the seed during no-tillage, simulating some of the advantages of larger-scale no-tillage machines.

15 Managing a No-tillage Seeding System

W. (Bill) R. Ritchie and C. John Baker

The overall success of a no-tillage seeding system will be no greater than the least successful component of that system.

Most of this book relates to the physical, biological, chemical and economic risks associated with equipment. But even the best equipment available will not provide optimum results if other input factors are not of equal or similar standard. Consequently, we must seriously consider the other factors required to put together a successful no-tillage seeding system that will fully minimize the risks. We obviously cannot provide a 'recipe' for fail-safe no-tillage seeding in every condition. Each successful package must be tailored to suit an individual farm, field or field component.

This chapter briefly highlights the range of factors that can influence the outcome from no-tillage crop or pasture seeding when undertaking a no-tillage system. A more detailed outline of the way such factors interact and how they determine the success or otherwise of a no-tillage system as a whole is given in *Successful No-tillage in Crop and Pasture Establishment* (Ritchie *et al.*, 2000).

Site Selection and Preparation

There is often little choice as to which field or fields will be no-tilled. In other cases,

however, farmers may be in a position to be more selective about fields, especially if they are just beginning to convert from tillage to no-tillage. If this is the case, it is important to review the criteria that should be considered.

Many who convert to no-tillage farming do so on areas with a history of intensive tillage that has resulted in poor soil structure, low SOM, low soil microbial activity, low earthworm numbers and possibly high soil compaction. Such conditions are not conducive to high yields from crops under any crop-establishment system. Although no-tillage would be expected to repair the damage over time, the technique may be disadvantaged in the short term. No-tillage may not be an overnight cure for such conditions, even though it is certainly a long-term cure.

If correctly managed, no-tillage can provide a sustainable method of crop production while at the same time allowing the natural processes of soil formation to continue. These processes take time, perhaps years and decades. Until a certain degree of repair has occurred, yields may even be reduced, especially if the farmer does not apply the best-known inputs into the system. But in other cases, where farmers have used high levels of inputs, including banded fertilizer, there are numerous field examples where crop yields have not

suffered, even in the first year; and most have steadily improved thereafter, often to new levels never before experienced in that field.

Best results for converting to no-tillage will come where a farmer has the option to select fields that have high potential returns from the outset. On an integrated pasture (sod) and crop farm, it may be most appropriate to begin a no-tillage crop rotation in a field that has been in pasture or lucerne for some time and contains soil in better condition than fields that have been cropped for many years.

On farms that have been entirely tilled in the past, fields that have been least affected by the destructive aspects of tillage should be chosen. It is unrealistic to expect to objectively assess the potential of a system such as no-tillage unless it has been given a realistic opportunity to show its true potential.

Effective soil drainage will have a major influence on soil condition. While no-tillage will improve the natural drainage capabilities of a soil over time, some artificial drainage may also be required. Well-drained soils or fields will provide the best results.

The importance of no-tillage openers being able to faithfully follow ground surface undulations has been outlined in Chapter 8. But, whatever the merits of any given technology in this respect, it will perform more effectively and will allow higher operating speeds to be used if the field is smooth. When tilling a field prior to converting to no-tillage, extra effort should be put into smoothing the final surface, a good investment for later no-tillage farming.

It is worth noting, however, that, over time, earthworm casting is capable of completely levelling ruts as deep as 75–150 mm (3–6 inches). But, of course, increases in earthworm numbers are a medium-term result of no-tillage rather than a short-term effect.

Seeding with no-tillage drills or planters will also be enhanced if fields are shaped so as to provide relatively straight lands. The firmer nature of untilled soils limits the

ability of many no-tillage machines to turn sharp corners. Pre-planning during subdivision can assist in this respect.

Weed Competition

Considerable discussion has centred on weed competition in relation to openers. It is important to remember that most of the operations during conventional tillage are designed to control competition with the crop arising from weeds (unwanted plant species). Consequently, the importance of the spraying operation(s) in no-tillage cannot be overstressed. Good management will include careful identification of the weed species, followed by careful selection of the most appropriate herbicides or other weed control strategy, such as mulching. Adequate planning is important to ensure that any residual herbicides used will be compatible with the immediate and other future crops, as well as desirable soil fauna such as earthworms. Some herbicides and pesticides, for example, are toxic to earthworms.

Having chosen the herbicide(s), additional management input is required to ensure that the specific chemical is applied at the correct rate of the active ingredient, with the correct rate of the carrier (usually water) and any other allied chemical (e.g. surfactant). Appropriate weather conditions during and for a specified period after spraying may be necessary. The particular stage and vigour of growth of the plants or size of leaf material may influence the activity of the herbicide. With some herbicides, there may be a minimum time period between spraying and drilling. In most cases, it is more critical to ensure that the timing of herbicide application is optimized with regard to that particular formulation and the stage of growth of the weeds unless there is residual activity from the herbicide in the soil or danger of the 'green bridge' effect (Chapter 3).

One principle that has repeatedly occurred has been the shift in troublesome weed species with continued years of no-tillage. Each weed species has an optimum pattern of tillage, crop competition and

moisture to establish. Almost all long-term no-tillage studies with weed observations have noted this distinct shift of both species and intensity. But the same and other longer-term studies show a significantly reduced total weed incidence with continued no-tillage systems that have used appropriate control and crop rotation strategies.

Pest and Disease Control

Most of the same management principles that apply to the control of weeds also apply to the control of pests and diseases. Accurate identification is essential to ensure appropriate and cost-effective control. Most importantly, it is necessary to recognize that some pests and diseases behave differently under no-tillage compared with tillage. It can often be quite misleading to assume that the control measures appropriate to tilled soils can be applied without modification to untilled soils. These principles apply to both pre- and post-drilling/planting management.

Chemical control measures may also be complemented by other management techniques, such as crop rotation, which is an essential tool in the development of sustainability. Not only is rotation effective to control pests and diseases, but it can also enhance weed control by allowing a wider range of herbicides to be used and/or enhancing the activity of particular herbicide treatments, modifying soil fertility and helping to raise SOM levels. Care must be exercised, because the chemical eradication of one unwanted pest species may be detrimental to other wanted species, especially earthworms.

Managing Soil Fertility

The development of no-tillage drilling and planting technologies that provide separate banding of fertilizer at the time of drilling/planting has opened the door to new opportunities for fertility management under

no-tillage. However, all of the old principles apply.

The key to cost-effective fertilizer use is accurate assessment of fertilizer levels and crop requirements. Soil and plant tissue analyses are useful tools in this process, as is accurate interpretation of the results. These results should then provide the basis for the selection of the most cost-effective fertilizer options, some of which might be restricted by machine limitations while others will not.

Considerably more site-specific research may be needed under no-tillage to determine the most appropriate fertilizer regime for any given combination of crop, soil type and climate under no-tillage. Fertilizer responses under no-tillage can differ from those under tillage in the same soil type. So the extension of experiences and research results under tillage may not necessarily be appropriate when applied to no-tillage systems. But plant requirements are generally not changed. No-tillage seeding with banded fertilizers offers an opportunity for increased application efficiency, but the total quantities of nutrients required, with the exception of nitrogen, may not be altered greatly.

Seeding Rates and Seed Quality

There is often considerable discussion about optimum seeding rates for no-tillage. Some have argued that seeding rates should be increased, presumably to counter some expected reduction in seed germination and/or seedling emergence. This practice has become known as using 'insurance' seeding rates. But doing so, even with no-tillage openers that have low emergence, can be counterproductive if ideal conditions are experienced that result in plant populations exceeding the optimum. And high seeding rates involve unnecessary extra seed cost.

There are few, if any, reasons for seedling establishment from no-tillage to be any lower than from conventional tillage if appropriate equipment is used. In fact, with advanced equipment and an appropriate

system, no-tillage has the potential for higher establishment percentages than tillage.

In any case, it is not how much seed that is sown that is important. Established seedlings are the final measure. Therefore, seeding rates should be based on an assessment of the degree of risk associated with any given situation, leading to a prediction of the likely effective seedling emergence (Ritchie *et al.*, 1994, 2000). The first factor to incorporate is the germination potential of the seed, which is specified on the seed certification data. Seeding rate can then be calculated using the following formula:

$$SR = \frac{TSW \times TPP}{EFE}$$

where: SR = seeding rate (kilograms per hectare); TSW = thousand seed weight (grams); TPP = target plant population (plants per square metre); EFE = effective field emergence (per cent).

The important principle is cost-effectiveness to produce the proper plant density. To be confident of achieving a target plant population, a farmer must use seed of good quality in conjunction with seeding equipment that provides reliable seedling establishment under a wide range of conditions.

Another important factor is accurate calibration of both seed and fertilizer output from the drill or planter. Because different lines of the same seed species can vary quite markedly in their seed weights and sizes according to the vigour of the crop and weather conditions and even the geographical location at the time of harvest of the particular line of seed, it is important to calibrate the metering mechanism when changing seed lines or varieties. A check on calibration should be kept during drilling/planting by matching seed and fertilizer used to the area covered if monitors are not available. Some seeders actually change their metering rates with changing ambient temperatures. The warming of the day from morning to afternoon may bring about an appreciable change in seeding rate with such seeders.

Farmer experience in Western Australia with the disc version of winged no-tillage openers showed that seeding rates for an equivalent canola stand could successfully be reduced from 9 kg/ha under tillage to 4–5 kg/ha with no-tillage using an advanced machine design (J. Stone, 1993, personal communication). The resulting saving in seed cost alone was equivalent to the additional machine cost. Prior to reducing the seeding rate, the experience of this operator from sowing at the higher rate with this no-tillage drill had been an overpopulated crop, which remained largely vegetative with poor crop yield.

Operator Skills

No-tillage is a relatively new technique to tillage farmers. When undertaking conventional tillage, farmers can draw on a long history of tillage experience from most soil types of the world, even if that experience was not personal. However, only a limited experience-base exists with no-tillage. Further, that limited experience-base has already shown that the two techniques are quite distinct and that new skills must be learned.

The 'one-pass' nature of no-tillage leaves little latitude for error. On the other hand, the range of implements and functions involved is much smaller. Therefore, a detailed knowledge of the key machines (sprayers and seeders) can be more easily gained.

Since soil physical conditions are more likely to vary under no-tillage from field to field, or even within a field, there is a much greater need for the operator to understand the principles involved under the conditions and to be able to adjust the machine accordingly. Of course, no-tillage drills and planters vary widely in their respective abilities to ignore soil variations by automatically adjusting to them, but all will require a reasonable level of operator skill to achieve optimum performance.

It is likely that in the future we shall see an increase in the use of electronic

monitoring and control of no-tillage drill and planter functions to enhance performance and reduce dependence on operator skills. It is also likely that the operation of no-tillage drills and planters will become a more specialized task, with an increased emphasis on operator training.

Post-seeding Management

A key catchphrase that has been coined for the modern age of intensive agriculture is 'knee-action farming'. The principle conveyed by this term is the importance of monitoring crop performance carefully and regularly at close quarters throughout the growth cycle. In many situations, this monitoring involves kneeling down to inspect the crop, rather than inspecting it from a distance in a standing position, and often with a magnifying glass in hand.

The 'knee-action farming' principle is not exclusive to no-tillage systems but is crucial to achieving consistently good cropping results, and is especially important to no-tillage because so many of the rules of crop husbandry differ from those common under tillage. No-tillage as a technique has suffered in the past from a lack of analysis of the reasons for poor results. Too often, farmers and researchers have been prepared to condemn no-tillage as a system on the basis of a poor result without determining the specific reason for the failure. This often contrasts with an acceptance of failure in a conventional tillage system on the basis of poor weather, an 'act of God' or just plain bad luck.

At times, there seems to have been a lack of realization that tillage crop failures due to severe wind or water erosion are not caused by unfortunate timing but an inherent failure of the tillage system to protect the crop from such a risk in the first place. No-tillage reduces some of those risks, but may introduce other risks of a different nature. For example, pest control becomes more important in some no-tillage situations because there is no physical destruction of their environment by the tillage process. All of this

means that a farmer must maintain vigilance over the crop to promptly react to crop management problems that might arise. It is a necessary advantage to have the skills to identify specific problems and how to solve them or know where to go for assistance. Regular, close observation is an important tool for 'knee-action' farming.

Planning – the Ultimate Management Tool

No-tillage is potentially a very flexible system. It provides farmers with the opportunity to respond at short notice to changes in soil or climatic conditions or market indicators. It is also a system, however, that benefits from effective long-term planning and regular reviews of the plan. The success of a crop may well depend on the implementation of a plan from several previous months. For example, crop rotation will influence weed management, pest and disease management, fertility levels and residue levels. Forward planning may well provide key opportunities to take advantage of these changing circumstances and markets.

Residue management for no-tillage systems is a case in point (see Chapter 10). Obviously, decisions at harvest of the previous crop will significantly influence the next phase of the farming rotation, which might occur several months hence. These connecting events apply to chemical use, equipment selection, fertilizer programmes, crop rotation and harvesting patterns, all of which emphasizes the role of forward planning as a management tool.

Another example is the application of lime to raise soil pH, which with no-tillage should take place at least 6 months in advance of drilling because without tillage there is limited opportunity to mix this low-solubility fertilizer with the soil.

Most other general aspects of managing a crop production programme apply, such as rigorous and regular maintenance of drilling, planting and allied equipment and

maintaining regular contact with suppliers and contractors to ensure that all components of the programme come together when required. Accurate record keeping is an integral part of any effective management programme.

Table 15.1 outlines the timing of many of the key in-field management decisions that need to be made in New Zealand if a no-tillage programme is to succeed. It is not intended as a recipe, but only to highlight the important issues. Since many of the

Table 15.1. An example of management steps for a no-tillage programme in New Zealand.

When	What to do	Implications
Any time before drilling	Ensure that drainage is OK	No-tillage will not rectify poorly drained soils
Any time before drilling	Determine how much risk you are prepared to take	Risk will be influenced by your choice of: herbicide (effectiveness is a function of conditions – poor conditions need better formulations); slug bait (heavy infestations and wet conditions need better formulations); pesticide (ensure you have identified the target pest and have chosen the correct treatment); drill (difficult conditions and small seeds need better technology); seed (difficult conditions will place more pressure on seed quality)
Any time before drilling	Check for pests that are not specific to no-tillage	Some pests may need treating before or at the time of drilling. Consider using insecticide-treated seed
Sometime before drilling	Subsoil to alleviate compaction if it exists. Best done when soil is dry	Use a subsoiler that does not disrupt the surface sufficiently to require tillage to smooth it out again. Slant-legged or shallow subsoilers are best in this regard
When heavy stock is removed from field	Smooth out hoof marks greater than 75 mm deep	Most drills will smooth out 75 mm deep hoof marks as they drill (some do it better than others). With deeper hoof marks use a 'Ground Hog', shallow subsoiler or leveller to knock only the surface humps off when the soil is somewhat crumbly on top
6 months before drilling	Apply lime if soil pH is low	Lime takes longer to act when there is no cultivation to incorporate it. Do not apply lime close to spraying time. Lime on plant leaves may affect the glyphosate and is slow to dissolve and wash into the soil
3 months before drilling	Take fertility samples	It takes time to get the results, analyse fertilizer options and take action. In long-term no-tillage 75 mm sampling may be more appropriate than 150 mm sampling
3 weeks before drilling	Aim to spray with glyphosate plus chlorpyrifos if springtails, aphid or Argentine stem weevil are a risk	Where farmers do not want to use the higher rates of chlorpyrifos, control of Argentine stem weevil may be obtained by waiting 3 weeks between spraying and drilling. However, you need to be aware that a low rate of chlorpyrifos may still be necessary to control springtails or aphids

Continued

Table 15.1. *Continued*

When	What to do	Implications
At least 2 weeks before drilling	Remove stock from the field (if it is in pasture that has not already been sprayed)	To be most effective, glyphosate should be sprayed on to as much clean, freshly growing leaf as possible. This also produces a heavy mulch, which will help control weeds and retain moisture, so long as the drill can handle the heavy mulch. If necessary, pastures can be grazed after spraying, provided that chlorpyrifos has not been used. Do not graze just before spraying, as leaf area will be reduced. Besides, fresh animal manure will reduce weed control and adversely affect some drill openers. The time needed to 'freshen up' a pasture will vary with growing conditions at the time
10 days before drilling	Check for the presence of slugs	Scatter short lengths of smooth timber about each field and leave for 2 or 3 days. One or two slugs on the underside of a 300 mm length of 150 × 20 timber indicates sufficient numbers to treat for
1 week before drilling	Pre-bait for slugs	This is only necessary for severe infestations. Moderate or low infestations can be effectively treated by applying baits at the time of drilling. With heavy infestations, apply half the bait 1 week before drilling and the other half at (or immediately after) drilling. Some drills can apply slug bait as they drill, either surface broadcast or 'down the spout'
1–10 days before drilling	Spray glyphosate (to control competition), together with chlorpyrifos (to control pests)	Tank-mix chlorpyrifos with the glyphosate where necessary to control pests. The longer the gap between spraying and drilling, the more crumbly the soil will become as roots decompose. But also be aware that soil dries more slowly after spraying because the plants are dead. In the event of rain after spraying, the soil may stay wet for longer. When cutting pasture for silage, wait 3–4 days after spraying before harvesting
1–3 days before drilling	Look at the moisture content of the soil	With most drills no-tillage works best when the soil is a little on the dry side. Being patient and waiting a few extra days often gives a better result
At the time of drilling	Preferably apply all of the crop's fertilizer requirements 'down the spout'. Crops like winter wheat and maize may also need further fertilizer after emergence	Only apply fertilizer 'down the spout' if the drill is sophisticated enough to band it separately from the seed (not mixed with the seed). Crop yield responses to placed fertilizer under no-tillage can be spectacular and there are generous limits to what and how much can be applied. But only a few advanced no-tillage drills do this. Where such drills are not available, avoid putting any fertilizer 'down the spout' at all, or be very careful to select non-burn-type fertilizers. Broadcasting is then the main option, although some people go

Table 15.1.

		to the trouble of drilling fertilizer alone first and then drilling seed at a shallower depth as a second operation
At the time of drilling	Ensure all seed is sown at the target depth and covered	This is sometimes easier said than done unless you have sophisticated no-tillage openers. Where openers are not so sophisticated, a level of risk must be accepted since germination and emergence will then be highly dependent on good weather, smooth fields and low residue levels
At the time of drilling	Apply slug bait	This is most important with spring drilling but may also be important in autumn. Moderate to light infestations of slugs can usually be controlled by applying slug bait either with the drill or as soon as drilling has finished. Get specific information from the experts on the effectiveness of different baits
In the first 3 weeks after drilling	Open slots and check for slug damage	There is often a small window of opportunity to apply slug baits after drilling if you have not already done so and you find slugs feeding in the slots
In the first 3 weeks after drilling	Open slots and check for twisted seedlings	Contrary to popular belief, twisted seedlings do not indicate fertilizer burn. They indicate low-vigour seeds. Do not be reluctant to have a sample of seed tested for vigour (not to be confused with germination) at a seed-testing laboratory. Almost every case of twisted seedlings we have seen has been caused by low-vigour seeds, which you would need to talk to your seed merchant about
In the first 3 weeks after drilling	Check for damage by Argentine stem weevil, springtails or aphids	All should have been controlled by tank-mixing the appropriate amount of chlorpyrifos with the glyphosate. But, if that did not occur, be extra vigilant because these are the main pests of no-tillage and can decimate an entire crop or pasture
In the first 3 weeks after drilling	Check for other pests not controlled with chlorpyrifos	Most normal pests of crop and pasture could also be troublesome under no-tillage. Be at least as vigilant as you would be with a tilled crop
4–6 weeks after drilling pasture	Check new grass plants for resistance to pulling (by hand)	When new grass plants are not easily pulled from the ground, they should be ready to be grazed lightly. Use light stock in large mobs for a short period, rather than set-stocking smaller mobs for long periods
After 6 weeks	Treat crops or pastures normally	That does not mean relax. It means that any problems that do arise will be no worse than under tillage. In fact, new no-tilled pastures, because of the firmness of the soil, can often be treated similarly to already established pastures. Utilization of turnips and swedes will improve because a greater proportion of the bulbs will be above the ground
At harvest	Spread crop residues evenly	Do not burn crop residues except where the drill to be used next will not handle them. Baling is

Continued

Table 15.1. *Continued*

When	What to do	Implications
		acceptable but will slow down the build-up of SOM. With some drills, chopping of residues will be necessary. Others can handle any residue in any form. Still others cannot handle any residues at all. Operators need to know what drill will be used for the next no-tilled crop before making decisions about what to do with the residues from the present crop
After 1–5 years of no-tillage	Examine your soil and bank balance	Both will probably be improved. Soil structure, health, porosity, organic matter and earthworm activity will be noticeably improved. Provided you have managed the system correctly and used the appropriate levels of inputs for your chosen level of risk acceptance, gross margins should increase progressively

Table 15.2. Comparative ownership and operating costs (US\$/ha) of no-tillage drills.

Area drilled (ha/year)	Simple low-cost drills	Conventional no-tillage drills	Sophisticated heavy-duty drills
50	69	107	182
100	45	62	95
200	32	39	53
400	26	29	30
600	24	26	23
800	23	23	20
1000	23	21	18

Simple low-cost no-tillage drills = US\$15,000.

Conventional no-tillage drills = US\$30,000.

Sophisticated advanced no-tillage drills = US\$65,000.

Other important assumptions: 24% marginal tax rate; inflation = 4%; interest rate = 11%; depreciation allowance = 12.5%; analysis period = 5 years; tractor costs are additional.

issues listed occur before the seed is sown, forward planning becomes one of the most important issues.

Cost Comparisons

No management analysis of a no-tillage system would be complete without an examination of the cost–benefits of choosing a drill or planter with different complexity, capability and cost. Economic studies (Baker, 1993a, b, c, 1994, 1995) show that,

as the annual use of a seed drill increases, a point is reached where there is little difference in the ownership and operating costs between simple low-cost machines and large sophisticated (high technology) expensive machines. Table 15.2 shows a comparison of costs. While the absolute costs and taxation rates shown in Table 15.2 will not be generally applicable and will soon be out of date, the relative values between the various options are likely to be more nearly universal.

At annual use levels of 50–100 hectares, the large sophisticated drills are prohibitively

expensive (US\$95–182/ha) compared with simple low-cost machines (US\$45–69/ha). However, from about 600 hectares per year upwards, the differences are negligible, at US\$18–26/ha and may even favour the larger machines. The data in Table 15.2 can be considered conservative as they do not account for increased seedling establishment or yields likely to result from using the more sophisticated machines. The costs do, however, account for higher operating speeds and lower maintenance for the more advanced machines. Saxton and Baker (1990), for example, found an advanced no-tillage drill with winged openers increased wheat yields an average of 13%. Calculations using a higher marginal tax rate than 24% and/or lower interest rates than 11% will result in the larger machines becoming economic at a lower annual usage than 600 hectares per year.

Summary of Managing a No-tillage Seeding System

1. The failure risk of a no-tillage seeding system can be reduced by ensuring a high level of input for all factors, not just the seeding equipment.
2. Choose sites that will offer a high potential return from the no-tillage system.
3. Chemicals generally replace tillage as a means of weed control and must be selected and applied with care.
4. Crop rotation can be an effective management tool when used in conjunction with chemicals to control weeds, pests and diseases.
5. Some no-tillage seeding equipment permits a wide range of options for fertilizer application. Accurate analysis of soil fertility levels and crop requirements will make full use of this benefit.
6. Using excessive quantities of poor-quality seed to compensate for poor drill or planter design or technique can be costly and ineffective.
7. No-tillage requires that new operator skills be learned but also offers the opportunity for greater operator specialization.
8. An otherwise well managed and executed no-tillage seeding programme can fail from poor post-seeding crop observation and follow-up.
9. Good planning of all aspects of the no-tillage programme is a key part of risk management.
10. Advanced no-tillage drills become economic at about 600 hectares use per year.
11. No-tillage is a short cut compared with conventional tillage. Do not short cut the short cut!

16 Controlled-traffic Farming as a Complementary Practice to No-tillage

W.C. Tim Chamen

Removing vehicle-induced compaction from the cropped area liberates crops and soils from unnecessary stress, enhances their performance and sustains production with the minimum of inputs.

What is Controlled-traffic Farming?

Controlled-traffic farming (CTF) divides the crop area and traffic lanes into distinctly and permanently separated zones. All implements have a particular span (or multiple of it) and all wheel tracks are confined to specific traffic lanes. It should not be confused with tramline systems, which just provide guidance for chemical applicators but do not offer permanent separation of wheels and crops. Figure 16.1 shows the system based on existing technology. In the longer term, it is likely that more specialized equipment will be developed that will improve flexibility and further enhance efficiency of the system.

Why Adopt a CTF Regime within a No-tillage Farming System?

The benefits of CTF

Soils not only physically support crops; they are also the medium through which

their roots grow and extract water, nutrients and air to sustain their development. Confinement or restriction of roots will almost invariably lead to a negative outcome. Removing vehicle-induced compaction improves and sustains the health of soils. More rainfall is absorbed and available to crop roots, which in turn are better able to explore and extract nutrients. Improved porosity also ensures effective gaseous exchange and drainage, both of which further improve the potential for optimum crop performance.

No-tillage improves many critical soil properties but some soils are still susceptible to wheel and hoof compaction, no matter how long they have been under no-tillage.

Machine performance is also improved by the avoidance of mechanically induced compaction. Variably compacted soils differ greatly in their strength and response to mechanical inputs. For example, this makes it difficult to achieve optimum performance of seed drill openers. Openers may work well in one condition or position on a drill and poorly or less well in others. A more homogeneous soil condition over the field provides greater machine precision. Soil responses are more predictable and vary less from point to point. Avoiding soil compaction diminishes the heterogeneity (variability) of soil properties both within and between soil types, making them easier to

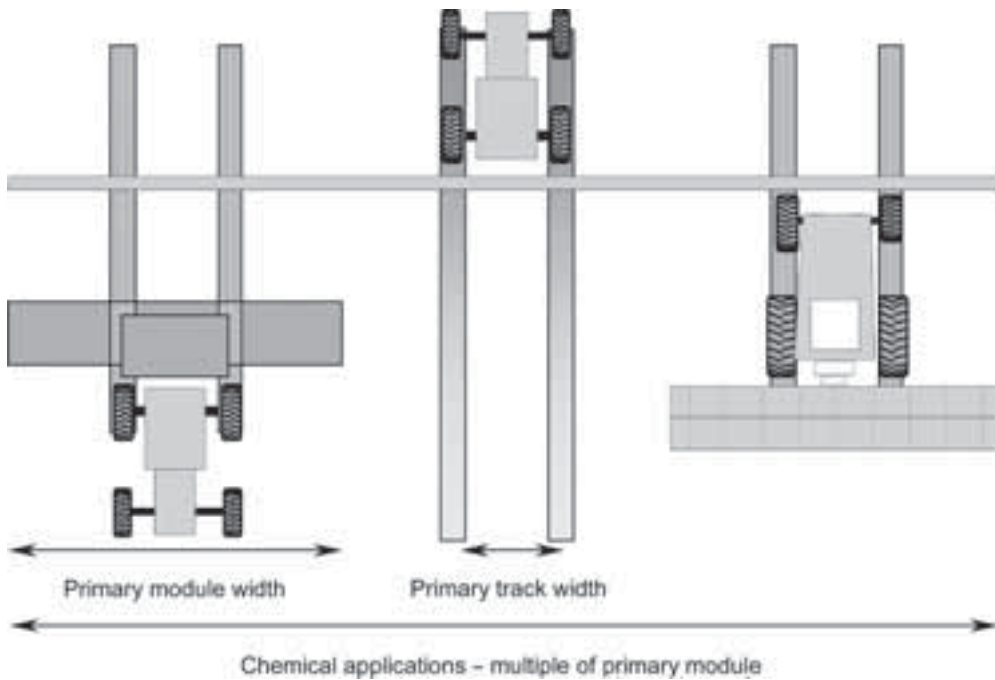


Fig. 16.1. A tractor-based controlled-traffic farming system showing drilling, spraying and harvesting. On this scale, all wheel tracks other than those used for chemical applications might be sown.

manage and more suitable for a wider range of crops under a no-tillage regime.

The effects of CTF on soil conditions

No-tillage farming systems may cause varying amounts of soil disturbance. Initially no-tillage concentrated on avoiding general tillage operations, but recent emphasis has added the importance of minimizing the disturbance created by the no-tillage tools (openers) themselves. Low-disturbance no-tillage is where drill and planter openers aim to disrupt the soil as little as possible – sufficient only to sow the seed and place the fertilizer, but otherwise leaving the soil almost as if it had not been drilled at all. Other forms of no-tillage involve aggressive shank, hoe or tined openers that leave the surface, and often deeper layers, in a disturbed state resembling the effects of minimum or reduced tillage.

Defining low-disturbance no-tillage is difficult. A general rule of thumb is that at least 70% of the original surface residues

should remain undisturbed after passage of the drill. But, for openers operating at 750 mm row spacing, 30% disturbance allows 112 mm either side of each row to be disturbed, whereas, at 150 mm spacing, only 22.5 mm either side of the row is acceptable.

In general terms, the greater the compaction applied to the soil, the greater will be the need for repair. No-tillage provides a large measure of remedial action by reducing the traffic intensity, avoiding soil disturbance and allowing the soil to restructure. However, removing the traffic altogether will allow this to happen in greater measure and more quickly. Central to the creation and maintenance of an improved soil structure is the minimization of disturbance, and, as we have seen from the above, the more aggressive the opener, the more disturbance there will be.

Unlike randomly trafficked soils, where the openers may need to create a seedbed as well as sow the seed, non-trafficked soils tend to retain their seedbeds from one season to the next, so that only seed and fertilizer placement is required. From all points of

view, the less the disturbance created during seeding within a no-tillage regime, the better, and CTF helps to make this possible. Where comparisons have been made between random trafficking and CTF, the research data often do not include details about the opener designs, and so the optimum no-tillage conditions for the trials may not always have been present, which may or may not have affected the comparisons.

Soil strength

The strength of soils is governed by a number of factors, some of which are interrelated and all of which have an impact on no-tillage. Compacted soils are stronger and have greater resistance to penetration than non-compacted soils, particularly when their water contents diminish (Blackwell *et al.*, 1985; Campbell *et al.*, 1986; Gerik *et al.*, 1987; Chamen *et al.*, 1990, 1992; Dickson and Campbell, 1990; Carter *et al.*, 1991; Unger, 1996; Radford *et al.*, 2000; Yavuzcan, 2000; Abu-Hamdeh, 2003; Radford and Yule, 2003).

In a 10-year experiment, one particular treatment subjected a moist (25–32% water content) Vertisol to a wheel load of 5 t in year 1 and 3 t annually thereafter for 5 years (Radford and Yule, 2003). Tillage to control weeds was used in the first 5 years of an arable rotation. At the end of the initial 5 years, no-tillage and controlled traffic were applied for a further 5 years to these same plots. The greater shear strength persisted in the 0–100 mm profile for over 3 years, while, in a treatment with repeated 5 t wheel loads in all of the first 5 years (compared with the 3 t after year 1), strength effects to 100 mm persisted for nearly 5 years after no-tillage was introduced.

These data suggest that randomly trafficked soils may exhibit high levels of variability in strength as a result of a history of indiscriminate wheeling. Although these differences may tend to diminish with time under a no-tillage regime, the natural amelioration in the top and most important few centimetres will tend to differ according to soil type, opener design and newly applied traffic. Added to this will be a general increase in soil strength arising from repeated

wheel passes. On some soils this may not be completely counteracted by structural improvements resulting from lack of disturbance or by a greater concentration of organic matter in the surface layers.

EFFECTS OF SOIL STRENGTH ON NUTRIENTS AND SEEDLING GROWTH. Increased soil strength reduces a crop's ability to extract nutrients and as a result some will be lost from the soil system. With any particular soil, strength variation is dominated by changes in water content, but strength at a specific water content is determined by its state of compactness. Denitrification caused by compaction is a source of nitrogen loss, and restricted rooting may cause poor phosphorus uptake (Wolkowski, 1990, 1991). Potassium uptake is primarily affected by aeration. Below an oxygen concentration of about 10%, uptake is impaired.

Denitrification may lead to fertilizer loss with no-tillage in wet conditions (Torbert and Reeves, 1995). When the soil is dry, uptake of N can be compaction-impaired by limiting root growth. This effect has been the cause of N loss, particularly under no-tillage, following N fertilization and heavy rainfall (Ball *et al.*, 1999). Denitrification and methane production were identified as one of the main constraints to the improved environmental performance of no-tillage compared with reduced tillage (King *et al.*, 2004). King *et al.* attributed this to an increase in the bulk density of the topsoil and to poor aeration.

Soil strength directly above emerging seedlings may also be an issue. Addae *et al.* (1991) suggested the following relationship:

$$Y = 90.4 - 3.58X$$

where:

Y = seedling emergence, percentage

X = soil strength, kPa

The maximum force that a wheat seedling coleoptile can exert is around 30 g and only when resistance is less than 25 g can 100% emergence be expected (Bouaziz *et al.*, 1990).

Compaction of the soil above an emerging seedling therefore reduces emergence, particularly if the soil is wet. Variation in the time to emergence is also often associated with soil strength variations (Brown, 1997).

EFFECTS OF SOIL STRUCTURE ON SOIL STRENGTH.

Increased soil strength can be attributed to changes in soil structure. It is a readily observable fact that compacted non-shrinking clay soils exhibit plasticity when moist and cloddiness when dry. They rarely display the friability and flow characteristics of non-compacted granular material. Consequently, randomly trafficked soils not only reveal large variations in penetration resistance, but they also react differently when disturbed. In some areas they will flow and in others they will smear or fracture into variably sized and often large aggregates. This is not easy to deal with when designing an opener to work consistently within a given soil type at a given moisture content. It is even more difficult when soil type changes across a given field. To overcome the problem of variable penetration depth, electromechanical control systems for no-tillage drills have recently been designed to cope with changes in soil strength and go a long way towards overcoming the problem (see Chapter 13).

One of the outcomes of tillage to remedy compaction, in an attempt to create a uniform but artificially structured seedbed, is interruption of natural soil structural-forming processes. This is despite the fact that the very mechanical processes being employed will themselves immediately render that soil more susceptible to the negative effects of random wheeling and other compacting influences. Therefore, although tillage temporarily makes the operation of seed drills relatively simple, it commits soil to a downward negative spiral of compaction and structural degradation and has never been a long-term answer.

Cockcroft and Olsson (2000) suggested that no-tillage and zero traffic could not avoid the problem of hard setting on some soils. Although biopores help the infiltration of water and more organic matter improves the situation, drainage and root growth can

still be impaired. A sustainable solution has yet to be found for these soils.

EFFECTS OF SOIL STRENGTH ON DRAUGHT FORCES AND IMPLEMENT WEAR. Although no-tillage aims to minimize soil disturbance, the force required to displace soil during sowing is still directly proportional to its strength. Chamen *et al.* (1990) reported a 25% reduction in energy requirement for no-tillage in non-trafficked compared with trafficked soil, despite a slightly greater depth of operation (56 mm in the non-trafficked compared with 50 mm in the trafficked soil). This is similar to reported reductions in energy for tine tillage in trafficked and non-trafficked soil (Lamers *et al.*, 1986).

A further consequence of lower soil strength is proportional reductions in wear on soil-engaging components. Lower wear saves on replacements and also saves on labour and downtime to fit new components.

While in tilled soils and some untilled soils it is often found that openers working behind wheels require replacement more frequently than elsewhere, in other situations the reverse may be true. When operating no-tillage drills in long-term pasture with good load-bearing ability in New Zealand, often the surface disturbance resulting from wheel slip by the tractor tyres loosens rather than compacts the soil and wear of openers in those wheel marks is reduced [Eds].

Soil structure

Avoiding vehicle-induced soil compaction can have a major impact on the structure-related aspects of water and gas movement in and out of the soil. Much research has concentrated on these characteristics. McQueen and Shepherd (2002) concluded that some soils brought into cropping from permanent pasture could suffer from soil deformation caused by traffic. Compaction, even on no-tillage soils, reduced water infiltration (Ankeny *et al.*, 1990; Meek *et al.*, 1990; Li *et al.*, 2001), soil porosity, saturated hydraulic conductivity (Wagger and Denton, 1989), air-filled porosity and permeability (Blackwell *et al.*, 1985; Campbell *et al.*, 1986).

On the other hand, minimal-disturbance no-tillage openers operating in silty soils in New Zealand have been shown to leave most indices of soil health (including soil structure) in a similar state to the original permanent pasture. Even after 20 years of continuous double cropping with no-tillage and random and repeated trafficking, there was no obvious effect on such soils compared with their pasture equivalents (Anon., 2000; Ross *et al.*, 2000, 2002a, b; Ross, 2001, 2002) [Eds].

Both air capacity and available water are primarily affected by bulk density, organic carbon and clay content, the latter being relatively more important in subsoils. Variability in air capacity and available water is highly dependent on bulk density and soil texture. In a clay loam, available water has been halved with an increase in bulk density from 1.4 g/cm³ to 1.75 g/cm³ (Hall *et al.*, 1977).

Reduced infiltration due to traffic compaction can increase runoff and erosion. Wang *et al.* (2003) measured a twofold increase in runoff on trafficked compared with non-trafficked no-tillage plots and an approximate threefold increase in soil loss.

Environmental improvements associated with non-compacted soils also relate to gaseous losses to the atmosphere. Reduced air-filled porosity due to compaction leads to denitrification in clay soils. Similarly, no-tillage and controlled traffic appear to preserve CH₄ oxidation rates (Ball *et al.*, 1999).

There is also evidence of improved water availability to crops on some non-trafficked, albeit shallow-tilled (100 mm) clay soils. Changes in matric potential at 150 mm depth over a 48 h period showed large fluctuations on a trafficked soil compared with relatively small changes on non-trafficked soil. The latter reinforces the importance of promoting natural soil structure through both no-tillage and controlled traffic (Chamen and Longstaff, 1995).

Campbell *et al.* (1986) working on a sandy clay loam found that, in the absence of traffic, the soil could be reclassified from being unsuitable to being entirely suitable for no-tillage.

The implications of CTF for no-tillage operations

RESIDUES AND RESIDUE HANDLING. Residues are a critical issue in no-tillage systems because they are not incorporated into the soil before the next crop is drilled. Indeed, many of the benefits of no-tillage accrue from this fact. It is preferable to leave the residues *in situ* on the soil surface to decay slowly and for both the residues themselves and their decayed products to be gradually incorporated into the soil by fauna such as earthworms. This is also advantageous in terms of nitrogen, which is often temporarily locked up by rapid organic matter decomposition. Residue management prior to and during drilling is therefore particularly important if the crop is to be sown without interference or subsequent adverse effects on germination and seedling growth.

The additional precision afforded by controlled traffic (see next section) should allow crop residues to be manipulated and placed more precisely, if required. For example, the tendency to use wider equipment is already initiating the design of more accurate residue placement methods by harvesters. Working from permanent wheel ways created as part of carefully prescribed routes and where future sowing lines are predetermined, residues could specifically be placed to avoid the new crop row.

With random traffic systems, crop stubbles and residues are flattened in an arbitrary way, resulting in their variable orientation to drill openers. Some openers do not perform reliably in these conditions; while others not only perform reliably but they utilize random residues to control the seed micro-environment. Controlled traffic avoids random stubble trampling and its associated variability. It is possible, for example, to develop the system where small grains have been stripped from straw that remains standing following the harvester pass. Both manual and assisted-guidance methods could then allow sowing between the standing straw rows and into soil that may only have a covering of the chaff and light fraction (Fig. 16.2).

There will be additional effects on residues from increased earthworm activity in



Fig. 16.2. Soil and residue conditions following grain stripping. Global positioning systems (GPS) and other precision guidance methods allow sowing to take place between the rows in a CTF regime.

non-trafficked soils. Radford *et al.* (2001) recorded an increase in earthworm numbers from 2 to 41/m² when all compaction on a moist vertisol was avoided. Pangnakorn *et al.* (2003) found a favourable differential of 26% in numbers of earthworms in no-till compared with cultivated soils and an additional 14% increase when traffic was removed.

Compaction restricts oxygen supply, nutrient intake and physical movement. Although the effect of additional earthworm activity is unlikely to have a direct effect on the sowing operation in terms of residues, the reverse is often true. Residues encourage earthworms and they in turn may improve seedling emergence, particularly in wet soils, primarily as a result of improved porosity. (Chaudry and Baker, 1988; Giles 1994).

Considering that there are increasing levels of CO₂ in the atmosphere and this

scenario is likely to continue, crop and weed residues and crop yields are likely to increase (Prior *et al.*, 2003). Improved management of residues will therefore be of increasing importance, not only to deal with the quantity, but also to avoid a temporary lock-up of nutrients and longer-term excessive acidity in the surface layers. This issue remains to be dealt with adequately.

WEED CONTROL. Traditional cultivation systems use a combination of cultural, chemical and tillage methods to achieve weed control. Weeds are always a threat to the sustainability of cropping, and they continuously evolve to overcome any particular means of control. The most recent example of this is the resistance of *Lolium rigidum* (annual ryegrass) to glyphosate (Wakelin *et al.*, 2004). Therefore, it can be argued that reducing the number of options for weed management is risky; but there are positive aspects too, some of which are aided by CTF, the most important of which is minimizing soil disturbance.

There are several approaches that improve weed control without tillage. One of the few defensible objectives of tillage is to stimulate weed seed germination so that the offending seedlings can be killed by a subsequent tillage operation. In the absence of such stimulation, the most widely practised weed control measure is to blanket spray with either selective or non-selective herbicides. CTF will make this more efficient because a greater proportion of weed seeds are likely to germinate during the inter-crop period. Seeds lying on a friable soil surface are more likely to germinate through intimate soil contact or by burial, either through their own activities (e.g. wild oats, *Avena fatua*) or external forces such as rainfall, frost, wind or the activities of soil fauna. After spraying, the aim is to avoid further weed seed germination, and crucial to the success of this is the minimization of soil disturbance by the no-tillage openers.

This approach has been effective in New Zealand. Troublesome weeds such as wild turnip had forced many farmers to stop growing forage brassicas by conventional tillage because of the difficulty in controlling volunteer wild turnip plants, the seeds

of which may remain dormant in undisturbed soil for up to 40 years. Even vigorous no-tillage openers often disturb sufficient soil within the rows to create rows of the weeds where none had existed before drilling. But use of the disc version of winged no-tillage openers or double disc openers, either of which minimizes surface disturbance, avoids the problem [Eds].

After drilling, it may be possible to utilize the close precision of CTF to target inter-row weeds that will either germinate as a function of their own activity (as described above) or be prompted to do so by shallow inter-row tillage with a light implement. Inter-row flaming, steaming, mowing and non-selective herbicides can then be applied where there is sufficient room between the rows. Vision guidance methods for doing this are now fast and reliable.

The efficiency of spray booms is likely to be improved by CTF systems. Most CTF systems use extended track widths and it is anticipated that future developments will provide additional boom support even further from the boom centre. Improved stability reduces roll and allows booms to be positioned closer to the crop or ground without fear of contact. The auto-guidance systems generally associated with CTF also reduce boom yaw, a feature associated with manual overcorrection of steering. Reduction of roll and yaw improve the application accuracy while diminishing the risk of drift.

OPENER DESIGN AND PERFORMANCE. The main implication of CTF for no-tillage opener designs involves the general reduction in soil strength in the absence of vehicle-induced compaction. This reduces the penetration and draught forces required between wheeled and non-wheeled areas. Chamen *et al.* (1990) found that a triple disc opener pressed into non-trafficked no-tillage soil by rubber buffers penetrated too deeply. A solution was to use a traditional single disc opener designed for cultivated soils. Thus it may be seen that no-tillage seeding on non-trafficked soils can be carried out with significantly lighter and less robust machines.

Non-trafficked soils tend to present a more friable seedbed regardless of the soil

moisture regime. This can have negative as well as positive effects. The positive effects are obvious and important, but hairpinning with discs may be a greater problem with CTF because there is less soil resistance to the vertical cutting of residues. Setting the discs deeper is unattractive because draught forces and soil disturbance are greatly increased. Other options include managing the residues to avoid their presence in the sowing line (Fig. 16.2) and using openers that do not create hairpinning or deliberately separate the seed from contact with hairpinned residues. The disc version of a winged opener places seeds to one side of any hairpins that the central disc may create, and eliminates this problem. The more friable nature of the soil under CTF will have largely a neutral effect on hairpinning with this opener [Eds].

Wide spacing of narrow tines works well in dry conditions but becomes unacceptable in moist soils because of the large wedges of residue left as the tines eventually clear themselves (see Chapter 10). Punch planters show promise if hairpinning can be avoided, but their potential has been limited by the high strength of trafficked soils. The greatest problems will be with moist clays, when fine soil and residues cling to every part of the opener. Experience of these conditions within a CTF regime is still limited and further use and customized opener development are needed.

On a more general note, the more friable seedbed structure associated with CTF should ensure that the firming devices of seed openers operate more effectively. As suggested by Baker and Mai (1982b) and Addae *et al.* (1991), firming should be around or under the seed, not above it. With CTF, a more homogeneous soil condition is likely to be presented to the opener and there will therefore be less need for compromises in depth settings between individual openers and less variation in seed covering. There will also be less wear, lower overall draught and reduced power and traction demands.

Figure 16.3 shows how two disc-type openers on the same machine can perform very differently, depending on whether

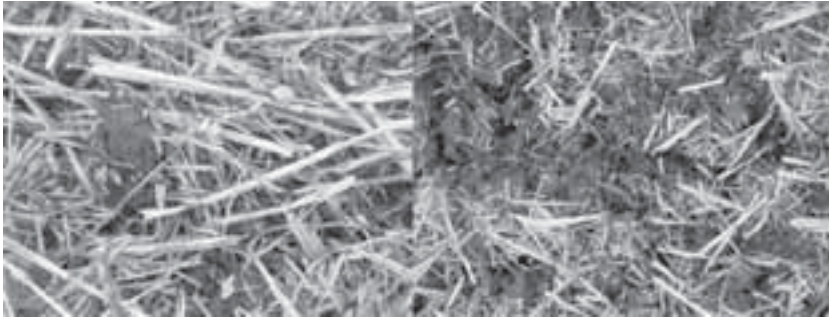


Fig. 16.3. Performance of two closely adjacent openers on the same drill working in a moist clay soil. The opener was behind the tractor wheels in the left photo and the seed is clearly visible on the surface, while on the right it was operating correctly in less compacted soil.

they are behind wheels or in between. In the absence of differential rutting from wheels, the soil surface will also be smoother. This reduces the potential for differences in opener performance, particularly where they are mounted in gangs. Openers mounted individually on parallel linkages will be less prone to depth variation where ruts are present, but a more level surface will still have a positive influence on their performance.

Consistent sowing depth is vital to avoid too shallow planting in dry conditions or too deep in others, and Kirby (1993) noted that the time to emergence was extended as sowing depth increased. Heege (1993) found that, in the range of cereal seeding depths from 25 to 45 mm, field emergence dropped from 82% when the depth varied by around 6 mm, to 50% when the variation increased to 20 mm. Heege and Kirby both found that rate of emergence affected subsequent growth, as did Benjamin (1990). They all suggested that differences in date of emergence were perpetuated and even exacerbated in subsequent growth. Although these differences may not be large enough to create differences in yield, they do make it more difficult to estimate crop growth stage for chemical applications. Additionally, this means that a larger proportion of the crop will be treated at the wrong growth stage and, as a result, suffer a greater setback.

In summary, fewer differences in soil strength and a more level surface will both help to make sowing depth more consistent.

This minimizes crop emergence time and makes subsequent management easier and more effective.

The implications of CTF for soils and crops

AGRONOMY. Provided that severely compacted soils are loosened before introducing CTF, it seems certain that the problem of poor initial crop growth and loss of nitrogen through denitrification will be reduced, particularly in the early years of no-tillage. Improved initial growth will be promoted by the lack of a compacted surface layer and encourages crop root growth, which explores and extracts nutrients from a greater proportion of the profile.

Australian farmers have found that row cropping is a natural extension to controlled traffic. This is possible because the position of each crop row can be planned in advance and achieved in practice with precision guidance techniques.

Seed rates have often been increased slightly with no-tillage, although rates of several crops have been actually reduced with advanced no-tillage openers (Baker *et al.*, 2001). Regardless, controlled traffic makes seeding more reliable and works in favour of lowering seed rates because the surface is more level and there is less compaction variation across the drill width. Without compaction, many soils form a stable fine crumb at the surface, which readily accepts seeds with minimal disturbance. This makes drill setting easier, reduces

irregularities in performance and avoids the need for increased 'insurance' seed rates.

A no-tillage farmer in the UK (Hollbrook, 1995) found that spring barley sown 3–4 mm deep was noticeably healthier than the crop sown at 40–50 mm. Shallow sowing resulted in the first node emerging from the coleoptile when it was 20–30 mm above ground rather than at the surface. This precluded the incidence of eyespot (*Cercospora*) and subsequent weakness of straws, which often resulted in crop lodging.

Slugs (*Deroceras reticulatum*) have frequently been a problem with cropping systems that retain surface residues, and particularly those with cloddy seedbeds and smeared and open sowing slots (Moen, 1989). Slugs attack crops in two ways – below ground, where they eat the seeds, and above ground, where they eat the young leaves. Openers that produce small clods mean that slugs can access seeds more readily, while open or smeared sowing lines allow them to move unhindered from one seed to the next. CTF has the potential to address these problems through the avoidance of 'cloddiness' and smeared sowing lines.

CROP YIELDS. Most research comparing trafficked and non-trafficked soils has been with systems using cultivation, but work on no-till in Scotland found that, even with fairly modest wheel loads, no-tillage yields were reduced. This occurred in the early years of no-tillage, but differences were absent by the fourth season, despite no actual reduction in bulk density on the trafficked soil (Campbell *et al.*, 1986). In the USA and in Argentina, soybean yields in no-tillage systems were reduced by between 10% and 39% with repeated but often quite modest wheel loads. Even where no-tillage had been practised for 7 years it was still possible to reduce yields as a result of newly imposed wheel loads (Flowers and Lal, 1998; Botta *et al.*, 2004).

RANGE OF CROPS. Although we have concentrated primarily on small-grain cropping, the introduction of CTF should make it possible to grow a wider range of crops

with no-tillage. No-tillage establishment of cotton, for example, was successful even in the presence of wheel compaction. Lint yields for no-tillage were only reduced in one year out of three, while those for transplanted tomatoes, albeit with strip tillage, were comparable at two sites in 2002. Strip tillage for melons resulted in marginally lower yields than the traditional method, but, with both tomatoes and melons, 'cloddy' soil conditions at planting/sowing were partly responsible for the poorer crop performance. A vegetable producer in Australia growing tomatoes, zucchini, melons, onions and broccoli predicted that CTF would allow him to establish these crops with no-tillage. Potatoes have also been grown successfully with deep mulches and no-tillage (Lamarca, 1998; Mitchell *et al.*, 2004a, b; Ziebarth, 2003, personal communication).

The possible constraints on cropping within a no-tillage CTF regime arise from a number of sources:

- Soil structure/crop interactions.
- Inexperience and perception.
- Machinery.

Because completely non-trafficked soil has until recently been largely unknown within farming systems, it is difficult to predict how some crops will react to these no-tillage conditions. Equally, there are very few data that might be used to determine whether crops such as carrots, sugar beet and potatoes will perform adequately in non-trafficked, non-tilled soil.

The only way that this might be determined is through the comparison of a number of soil parameters, such as bulk density, penetration resistance and porosity. For example, does the bulk density of a given non-trafficked non-tilled soil exceed that of its cultivated counterpart for a particular crop? In addition, within what soil environment will a root crop perform equally to that of the cultivated norm? Many of these questions remain unanswered. We shall also have to be aware that considerable soil disturbance is often experienced during the harvest of root crops. Although this would at least partly interrupt the no-tillage cycle, it would still be advantageous for the

remainder of the rotation and for establishment of the root crop. Controlled traffic would also minimize the repair needed after harvesting and ensure a quick and effective return to no-tillage.

The crops that we can probably grow now under a CTF regime with a proven agronomy based on no-tillage include:

- Wheat
- Oats
- Sorghum
- Oilseed rape
- Soybean
- Field beans
- Dryland rice
- Barley
- Rye
- Millet
- Maize
- Dry peas
- Linseed
- Cotton

This range is necessarily more limited than mentioned previously, and further technological developments and in-field experience are needed before more crops can be considered. However, given the characteristics of these crops and the typical climatic conditions under which they have been successful, it would be quite rational to extrapolate to other crops and climates in locations where CTF no-tillage farming has not been extensively attempted.

Making CTF Happen

Basic principles

There are several principles involved in CTF:

1. Forward planning.
2. Matching of vehicle track widths.
3. Matching of single (primary) or multiples of implement widths.
4. Discipline.

These principles will be outlined in the following sections, but far greater detail can be found in *Tramline Farming Systems*, published by the Department of Agriculture, Western Australia (Webb *et al.*, 2000), in conjunction with the Grains Research and Development Corporation.

Forward planning and machinery matching

Planning is probably the most important aspect of conversion to CTF, because it ensures, amongst other things, that the cost is kept to a minimum. Some farms may be able to convert within 12 months; others may require planning and change extending over several years. In the context of this book, it is assumed that the end point of transition is a no-tillage crop establishment system, but the starting point could be mouldboard ploughing, secondary cultivation and drilling. There must therefore be an initial commitment to a significantly lower input system. In some ways, changing from an extensive machinery system makes the economics easier because the excess machinery can be sold and appropriately sized new or second-hand equipment purchased, probably at little additional cost. It will also entail a reduction in labour. The economics, however, will be dominated by the change to no-tillage rather than to CTF. If a minimum- or no-tillage system is already being used, the transition may have to be planned more carefully and over a longer timescale because fewer costs will be lost from the system, but returns will still be improved.

The width-matching process

The objective is to match all implement working widths, on the one hand, and machine track widths, on the other. The purpose is to minimize costs and number of wheel tracks per unit area. The cost factor means that most transitions will start with examination of existing equipment to consider its adaptability. As an example, take a small farm growing grain crops with a minimum-tillage system that has a 3.5 m wide cultivator, a 5 m wide roll and a 3 m wide drill; the cereal harvester is 6.1 m wide and chemicals are applied with 12 m booms. Tractors are on track widths varying from 1.5 to 1.8 m and trailers have a track of around 1.8 m; the harvester is on 2.8 m. In effect, nothing matches up with anything in

terms of controlled traffic (Fig. 16.4, left). The tractor wheel track settings can, however, be changed to 1.8 m (to match the trailers) relatively easily.

Two challenges remain – the track width of the harvester and the choice and width of no-tillage drill. If the 6.1 m harvester is to be retained, the drill should be 6 m wide (to ensure that the harvester gathers the entire crop on most occasions) and the cost of this will need to be budgeted, with allowance made for the second-hand value of the existing drill, cultivator and the rolls (the economics of CTF will be studied more closely in a later section). It may also be possible to sell one tractor, but one of the remaining tractors must be capable of pulling the proposed replacement drill or a new (larger) tractor will have to be purchased.

The harvester track width cannot easily be changed and these wheels will be the one set that extend outside the primary

track width. Their position, however, is known and they will not necessarily cause damage every season because soils are often drier at this time (and therefore able to withstand more weight) than at sowing. If compaction and surface rutting occur, they can be repaired with a subsoiler having tines positioned so that they loosen just the additional width imposed by the harvester. A 6 m system as described will create wheel ways that cover around 16% of the area, depending on the width of the tyres used. Providing the wheel ways are well maintained, it may be possible in the longer term to fit narrower tyres.

On a larger farm, an alternative might be to use a 'twin-track' CTF system. This largely eliminates the harvester problem, while maintaining wheel track settings more or less as standard. Figure 16.5 shows that the system works by straddling the harvester across adjacent passes of the primary

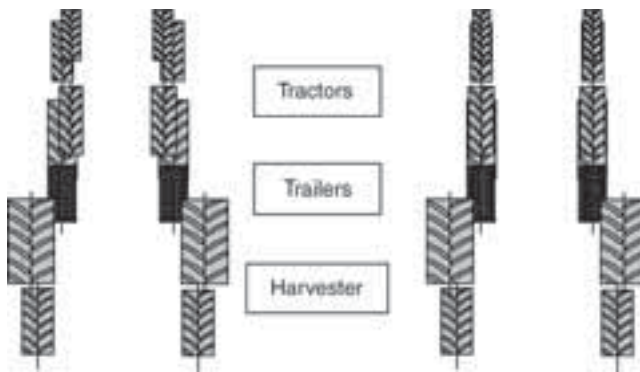


Fig. 16.4. Placing all the equipment in the example around a common centre line (left) shows that it is only the harvester that has a significantly different track width. Available settings on the tractors will allow them to be aligned with the trailers, as indicated on the right, with only the cost of time.

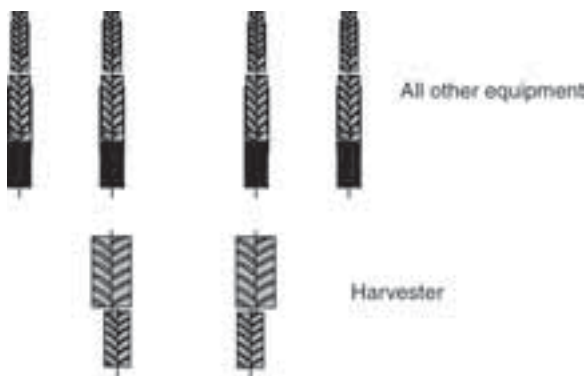


Fig. 16.5. Twin-track CTF system, where the harvester straddles single tracks of adjacent pairs of tractor tracks. Primary implement width is determined by the addition of the tractor and harvester track widths.

tracks. The primary implement width is determined from the simple addition of the common track width of the tractors, trailers and chemical application equipment, plus the harvester track width. In the example above, primary implement width would be: $1.8 + 2.8 = 4.6$ m. The harvester cutting width can be any multiple of this; in this instance, the most practical would be 4.6 or 9.2 m. The drilling width, however, can only be odd multiples of the primary implement width and this probably limits it to a single multiple. Chemical applications can be any multiple of the primary implement width if the primary tracks are used, e.g. 4.6 m, 9.2 m, etc. If the chemical application equipment is on a wide axle and runs on the harvester tracks (to improve the stability of the applicator), the width of the chemical application equipment can only be even multiples of the primary implement width.

Presently none of the implement widths quoted above is standard, so some adjustment to the primary track width might be needed even in a twin-track system. For example, if the primary track were narrowed to 1.7 m, this would correspond with available harvester widths (9 m) and chemical application equipment (18 m, 27 m, 36 m). Alternatively, the track settings could be 2 m and 3 m, giving a primary implement width of 5 m. The harvester cutting width should be slightly wider than the calculated

width to ensure capture of the entire crop in all circumstances.

A further method of matching is to align all field machinery on the same track width as the harvester because, as previously mentioned, this machine is difficult to alter. Unfortunately, the harvester is probably the machine with the widest track, and with current designs this will mean a primary track width of around 3 m for all vehicles and implements. This is common practice in Australia (Fig. 16.6), where there may be less need to drive on highways and where rural areas have relatively low population densities. In Europe and other parts of the world with high population densities and often-narrow roads, much greater difficulties are likely. However, because no-tillage reduces the number of field operations and future spray vehicles may have 'on the move' variable track widths, the extent of the problem should diminish considerably. It may only be the harvester and sowing machine and associated tractor that have the 3 m track setting on the road. The advantage of this system is that there are few constraints in terms of primary implement widths. With very wide machines, some means of extending the harvester's unloading auger may be needed to ensure that the transport unit can be reached in the adjacent traffic lane.

A further alternative similar to 'twin-track' for smaller farms is for the harvester



Fig. 16.6. Example of an Australian system with a 9 m primary module and a 3 m primary track width (Webb *et al.*, 2000).

to span between the same wheels of adjacent tractor passes, as shown in Fig. 16.7. The basis for this is:

Primary implement width	=	harvester track width
Primary track width	=	harvester track width/2
Harvester cutting width	=	harvester track width $\times 1.5$
Chemical application width	=	any multiple of primary implement width

This system potentially introduces a large number of wheel tracks, but some of these may only be used once a year for crop sowing and most could be sown, as described later.

So far, we have dealt primarily with the systems used for small-grain crops, but the principles of no-tillage can be applied equally to most other crops. Although little research has been done on no-tillage for vegetable crops, improved potential may exist within CTF systems, as discussed later.

Field layout and system management

Orientation and layout of controlled traffic wheel ways are all part of the planning process, and each individual area or block of land needs to be considered independently. Detailed field maps are an essential part of this planning, by measurements, historical records or aerial photographs. Topographic data are also valuable, particularly on farms with significant slopes. Changes in soil type across a property are likely to be of lesser significance than with random traffic systems, but it will still be useful to know these boundaries, particularly with respect to drainage. With regard to drainage, it is essential that any installed drainage systems are operating properly or problems corrected before installing a CTF system. This is also true for soil structural remediation. If inspection reveals a pan layer, fissuring of the profile should be attempted according to the guidelines suggested by Spoor *et al.* (2003).

The principal aspects to consider in any CTF layout are:

- Orientation of permanent wheel ways in relation to:
 - length of run;
 - slope and water movement;

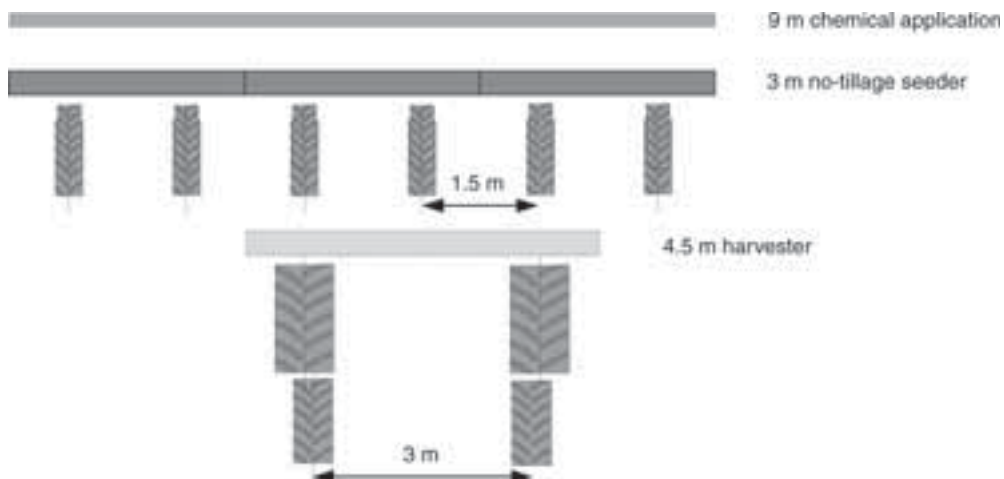


Fig. 16.7. A controlled traffic machinery system for small farms. The 1.5 m primary track width is spaced at 1.5 m intervals and thus any pair of wheel tracks can be used by all equipment other than the harvester.

- field shape and short rows;
- extraneous objects (trees, pylons, ponds, etc.);
- field drainage system.
- Wheel-way management and field access.

Orientation of permanent wheel ways

In most situations the longest length of the area being considered is chosen for the orientation because this improves field efficiency by reducing the number of end turns. The length of run that this creates must also be considered in respect of any significant field slope. Although water infiltration on the soil 'beds' is likely to be improved significantly compared with traditionally managed fields, water will still tend to run along and erode the wheel ways, particularly if they run uninterrupted over long distances and are orientated up and down slopes. In Australia, where CTF is widely practised and where rainfall events can be very heavy, orientation of operations has become more flexible with CTF. Both up and down and across the slope can work, whereas with random traffic across-slope or contour layouts predominate.

CTF orientation must also consider the presence of any drainage system, and particularly one that involves mole channels. The latter will run predominantly up and down slopes and the aim with a controlled traffic system is to run parallel to them. The danger with repeated wheeling across the mole channels is that they may collapse prematurely. Running parallel to the moles will mean crossing the drains themselves, but it is unlikely that these will be damaged, partly due to their depth but also because they are often backfilled with gravel. If the wheel ways run parallel to the mole channels, although there is a danger that some will be coincident with and may damage them, the overall effect on the drainage system within a field is likely to be minimal. Running parallel will also ensure that the mole channels can be redrawn without complete disruption of the wheel ways.

For more information on drainage systems, see Spoor (1994).

A similar approach is adopted with a row of pylons going across a field; in this case, they may be used for the orientation and as a line to set up the first wheel tracks. Unlucky indeed would be the farmer who has both a drainage system and pylons with completely different orientations! The compromise would have to be with the pylons. Experience with either drainage systems or field 'infrastructure' is limited, because CTF has yet to be adopted in areas where these situations occur extensively.

Wheel-way management

The potential for wheel-way erosion can be countered in a number of ways. As a first principle, the wheel ways need active management from the outset; they cannot be allowed to sink or rut differentially. They should be filled as required by drawing in soil from the surrounding area, particularly in the early days of establishment, and particularly if the soil has been deep-loosened recently. Within a tillage regime, these recommendations could be met coincidentally during the creation of a false seedbed for weeds. However, in the context of no-tillage, a customized narrow unit (Fig. 16.8) might be used if rutting or plastic flow of soil out of the wheel ways has occurred. This implement should not be used too frequently, however, as the edges of the beds may become rounded and cause uneven sowing depth.

If weed or erosion pressures on bare soil become unacceptable or, due to machinery constraints, the wheel tracks take up a large proportion of the area, crop may be established within them (in general, this applies only to those tracks that will not be used after crop sowing). The roots of plants established in these tracks will often explore laterally and find their way into the main crop bed. As a result and although they perform less well, they do mature in unison with and add significantly to the main crop yield. This is not the case for sown wheel ways that are used subsequently for crop management. In these the plants are often



Fig. 16.8. Rolling maintenance tool used to deal with plastic flow of soil out of the wheel ways. This would not normally be used on more than an annual basis (J. Grant, 2001, personal communication).

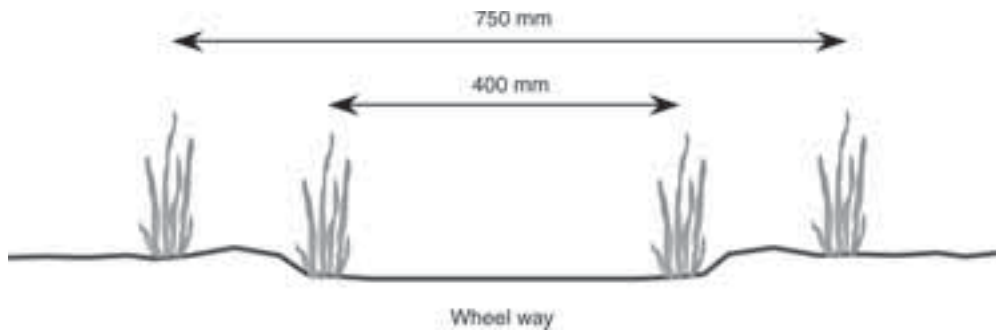


Fig. 16.9. Example of how a cereal crop might be sown on a wheel way. The nominal 250 mm spacing is modified to 400/175 mm to encourage roots of the plants in the wheel way to access the adjacent bed.

dwarfed by repeated wheeling and are late to mature. Where wheel ways are sown within a narrowly spaced crop (300 mm or less), the row spacing may be altered slightly, as illustrated in Fig. 16.9. The openers will need to be set very specifically to deal with this situation and the wear rate on them is likely to be higher. To date there is limited experience with this technique and growers will need to use some field experimentation initially, but this technique has the added advantage of temporarily marking the wheel ways.

In some instances, further active management of the wheel ways might be needed on slopes to ensure that water gathered within them does not reach erosive potential.

This could be achieved by introducing diagonal channels at regular intervals, which divert water into the beds alongside.

The second principle of wheel-way management is to avoid water standing in or flowing along them. To a large extent, the first of these problems can be avoided by attending to active management, but low spots in the field or areas of poor natural drainage can also create this situation. Orientation should aim to avoid low spots, but this will not always be possible and an alternative in the form of modifying the wheel-way edges, as described above, may need to be introduced.

Wheel-way erosion may also be reduced by a buffer strip part-way downslope.

This might also provide an area for beneficial insects and, if sited correctly, address 'short row' issues.

Guidance systems

Fundamental to any controlled-traffic farming system is a means of ensuring that the wheel ways are not only orientated but also positioned correctly at the outset. Traditionally, positioning has been achieved with machine-mounted hardware that provides an adjacent parallel marking line offset by the required distance. The driver then uses this line on the next pass to position the machinery correctly. This works well with modest machinery widths but, when these approach 10 m or more, the size, strength and durability of the equipment become a significant factor. Offset loads can also be a problem if the marker engages with the soil, and maintenance costs can also be high. It is an even greater problem under no-tillage because the marker has to make a visible line in untilled and often residue-covered soil, and this is difficult. Markers have relatively low precision and introduce errors that are cumulative pass to pass. An alternative, but still with cumulative errors and poor precision, is to place a closed-circuit video camera on the extremity of the implement, with pictures relayed to a screen in the driver's cabin. This requires that the driver continuously monitor the screen to keep the machinery on course, as he or she would with a marked line.

An increasingly available and attractive alternative is electronic systems based on a differential global positioning system (DGPS) using satellite signals. There is a wide range of available costs, depending upon the degree of accuracy delivered. With CTF systems, an accuracy of ± 3 cm is desirable, with a peak error of ± 5 cm if wide-row crop operations are planned. Such systems can also be coupled directly to the vehicle's steering to provide auto-steer capability for both straight-line and curved parallel tracking. Automatic steering allows drivers to concentrate on the implement operation, relieves them of the

constant stress of driving to a mark and also avoids excessive steering corrections, which can adversely affect machinery operation. A further advantage, particularly with wide equipment, is that any pass can be driven in any sequence, because the positioning is absolute, since it does not rely on a mark from the previous pass. Drivers can skip every other pass, for example. This makes turning at the end easier and has the added advantage that field completion can be at the start point, which is normally the point of field access.

It is also important to note that the implement lateral offset feature found with a number of satellite guidance systems cannot be used with CTF. This feature compensates for an implement that does not trail centrally behind the tractor by shifting the tractor appropriately on adjacent passes. If this were used with CTF, it would move the vehicle off the permanent wheel ways. Any misalignment in a CTF system must therefore be dealt with physically on the tractor or implement and this can create a significant challenge on side slopes. Trailed equipment may need some wheel steer to overcome this problem.

Economics

There are a number of ways in which the economics of CTF systems can be assessed and all will give different answers. Every property, circumstance and range of machinery will be unique and the economics of change will be very specific. The aim in this chapter, therefore, will be to establish the principles and the cost/revenue centres rather than entering into detailed cost analyses that provide only a single hypothetical solution. This approach also concentrates on the transition from no-tillage seeding in the presence of random traffic to a similar but controlled traffic system.

Economics centre on:

- Planning and transition costs and their timescale.
- Fixed and variable costs of the CTF system employed.

- Change in output.
- Management costs.

Transition costs and timescale for change to CTF

Planning is the key to minimizing costs. And yet the cost of planning itself is difficult to quantify. A typical consultancy fee for CTF conversion in Australia is around US\$75 per hour. There will, however, be many growers who will study the subject carefully and put a plan together themselves, the costs of which will be absorbed within normal overheads. But serious consideration should be given to employing the services of experts to determine the most efficient field layouts. Changing a layout after installation is not an attractive proposition and is very wasteful of time and resources, as well as resulting in a loss in productivity.

The planning process will involve taking stock of existing farm equipment and how much it can be applied within the new regime. A clear picture of the new CTF cropping and machinery regime needs to be clearly identified at this stage before transition costs can be estimated. The transition costs fall into three main categories: (i) those associated with changing the implements or machines; (ii) those associated with changing wheel-track settings; and (iii) those associated with guidance:

1. Changing machinery might include buying new, as well as discarding old equipment. If a change to no-tillage is being made at the same time as adoption of CTF, the equipment requiring attention will be greater, but an opportunity exists to integrate the full range rather than just parts. With CTF, the no-tillage drill will experience lower penetration and draught forces and as a result there will be lower power demands on the tractor, so some longer-term savings may be possible. Centralization of the harvester cutting platform may also be necessary because many are offset to assist unloading. The other main aspect to consider is the

matching of implement widths, on the one hand, and wheel-track settings, on the other.

2. The cost of changing wheel tracks may be in the range US\$750 to US\$4000 (Webb *et al.*, 2000) and reflects considerable diversity in machine designs, axle configurations and wheel equipment. This cost will also vary considerably depending upon the type of system adopted, for example single- or twin-track, as described earlier. For single-track systems, the cost is likely to be greater because all equipment will probably have to be matched to the wider track setting of the harvester. Such conversions are now available for some tractors, with total costs for front and rear axles being in the region of US\$10,000. Most other equipment can be modified locally or in the farm workshop. For twin-track systems, the costs may be confined to the labour required to alter the position of rims on centres or swapping wheels from side to side, for example.

3. Costs for guidance systems can be as little as the time required to make up marker arms from existing farm equipment to around US\$50,000 for a satellite system delivering auto-steer with a mean offset error of around ± 3 cm. The market and therefore the cost structure for these satellite-based systems is changing rapidly and to such an extent that the full cost of the system may not necessarily be attributable only to conversion to CTF. Many farmers are now purchasing these systems within conventional practice as a means of improving the accuracy of their operations, as well as establishing tramlines for chemical applications.

Not only does the latter give greater flexibility, but it also precludes the need to establish marks within the crop. Traditionally these have been installed by special equipment on the drill that leaves lines unsown at the required intervals.

To introduce CTF, an existing system might be upgraded from perhaps ± 25 cm manual to ± 3 cm auto-steer. The additional cost of this would be in the region of US\$17,000.

The timescale for change will depend on the investment that has been calculated;

the greater the investment, the shorter should be the timescale. This is because the greatest benefits will only be realized when a complete CTF system is in place. These benefits are dealt with in the section on outputs.

Fixed and variable costs

Fixed costs are generally considered to be regular labour, machinery, rent and general overheads, while chemicals, seeds, fuel, wearing parts, contractors and casual labour are considered to be variable (Nix, 2001). With CTF, we would expect the main impact to be a lowering of fixed costs, and particularly those related to labour and machinery. The marginal labour benefit from CTF will be less than but additional to the marginal labour benefit from changing to no-tillage in the first place.

Although it would be easy to attribute CTF with improvements in field efficiency due to better guidance, this can now be achieved equally within conventional practice using 'tramline' systems on drills or through satellite guidance, and is therefore not considered as a CTF benefit. The main impact of CTF on labour in a no-tillage system will be a reduced demand during drilling, which could be slightly faster (conditions permitting) as a result of lower draught forces on the drill. Unless a contractor is employed for this task, the farmer is only likely to experience a timeliness benefit in the short term. In the longer term it may be possible to increase the land farmed with a given labour force or lose some labour costs if several are employed during drilling.

Changes in variable costs centre on seeds, fuel, wearing parts and chemicals, all of which should be reduced. Typically, power demands for drilling at any particular speed are reduced by up to 25%, including the lower rolling resistance that can be attributed to working on the permanent wheel ways rather than on the crop bed. Due to the improved soil conditions, lower seed rates may be possible with less risk, although this issue should also be handled by improving the drilling methodology

rather than relying on CTF alone to make up for deficiencies in drilling equipment or technique. Savings on wearing parts are more difficult to predict but will increase the longer the soil is under no-tillage.

Chemical costs are likely to be reduced principally through greater precision and the ability to inter-row band-spray with non-selective chemicals while simultaneously applying selectively to the crop row. Although such a system is not exclusive to CTF, the well-maintained wheel ways offer greater potential. If one considers that the cost of protection chemicals for wheat grown in a temperate region approaches 50% of the total cost of seed, fertilizer and spray (Nix, 2001), then any saving on these chemicals is likely to have significant cost implications. Equally, a reduction in chemical inputs, or at least input of less environmentally damaging chemicals, is an added benefit. We may also presume that fertilizers applied in a CTF regime will be more efficiently utilized and, although this may not be a cost saving to the farm, it will result in an improved yield (discussed below) and a lower risk of off-farm pollution of water-courses.

Change in output

Reviewing research undertaken over the past 30–40 years on soil compaction with 17 different crops showed that yields under CTF in both tilled and non-tilled conditions had increased in the range 9–16% compared with random traffic. The less extensive data quoted for no-tillage systems suggest a more modest level of improvement; a safe figure may be around 10%. Soil type, cultural practices, crop rotations and the percentage area of land taken up by permanent wheel tracks will obviously moderate these percentages, and the crop row spacing will further influence the effect. To determine what happens in practice, each individual case needs to be considered and the following suggests an approach that might be taken.

Taking the 8 m system considered earlier and a close-spaced row crop such as

wheat (250 mm in this case), the following is assumed to apply:

Primary implement width = 8 m
 Primary track width = 3 m
 Chemicals applied at 24 m width
 Two out of every three primary tracks
 are sown

Assuming that crop yield is improved by 10% only on the non-trafficked area and that the harvester will have wheels around 750 mm wide, the number of rows affected by wheels will be $3 \times 2 \times 4 = 24$ rows out of a total of 96. There will be no improvement in yield on these rows and therefore the net improvement will be 7.5%. This is actually a conservative estimate because conventional systems usually have tramlines where at least two rows will be missing within a 24 m width.

In-field management costs

The main ongoing management cost to sustain field operations is likely to be that associated with the permanent wheel ways. As indicated earlier, a customized small implement (Fig. 16.8) may suffice for this task, but within a no-tillage regime this represents an additional pass, usually carried out after harvest. Experience suggests that this may be needed in the early years of conversion and when any operation has to be carried out in wet conditions. In some instances, this may only be needed on the chemical application wheel ways.

Summary of costs and returns

Table 16.1 provides an overview of the aspects considered in the foregoing text and attempts to quantify a number of the variables. As stressed earlier and confirmed by Uri (2000), the variables are so numerous that any fully calculated example involving conservation or no-tillage systems will only provide a specific solution unique to a particular situation. It is better, therefore, to

have the tools and a procedure to calculate rather than to give a single answer.

The magnitude of these costs can be put into context by examining some of the benefits. A world price for wheat of US\$100/t and an average yield of 4 t/ha increased by 7.5% on 500 ha, equates to an additional income of US\$15,000 per annum. At 2001 prices, a 20% reduction in tractor size from 134 kW would give a saving of around US\$17,000. The net benefit from these two items on 500 ha is US\$32,000 at the end of the first year.

Detailed analyses on a regional basis are offered by a number of authors and the reader is referred to these specific studies for further information. Gaffney and Wilson (2003), for example, suggest a net benefit of US\$15–25/ha for a change to CTF within a no-tillage regime on a vertisol in Queensland, while Mason *et al.* (1995) for the same scenario in the South Burnett of Australia suggest a net improvement of US\$75/ha.

Summary of Controlled-traffic Farming as a Complementary Practice to No-tillage

1. Controlled-traffic farming (CTF) is a crop production system in which the crop zone and traffic lanes are distinctly and permanently separated. In practice, it requires:
 - a. use of the same wheel tracks for all field operations;
 - b. all machines to have the same wheel-track setting;
 - c. all implements to have a particular span or multiple of it.
2. CTF relies on good guidance systems to install and keep the permanent wheel ways in the same place from year to year. The main systems used to do this are:
 - a. physical markers, which provide a means of positioning the next pass, which, if integrated with seeding, may be used to introduce guide rows for later use;
 - b. closed-circuit television (CCTV) video cameras with an associated display in the driver's cabin;

Table 16.1. Factors and variables that impact on the economics of changing from a random traffic to a controlled traffic no-tillage seeding system, their likely magnitude and level following transition.

Factor/variable	Costs, US\$	Savings/benefits, %
Consultancy for CTF field layout	75/h	
Drill price (from Uri, 2000)	6,400	11
DGPS guidance with ± 25 cm pass-to-pass accuracy	2,400 ^a	
DGPS guidance upgrade from ± 25 cm to ± 3 cm accuracy ^c	15,400 ^b	
DGPS guidance to ± 3 cm with automatic steering ^c	5,400–10,200	
Axle conversions to 3 m:		
Tractors – per tractor with full warranty	750–4,000	
Drill, chasers or trailers, per item	5,000–7,000	
Self-propelled chemical applicators with full warranty (Not needed if tractor mounted. Also, many North American special-purpose vehicles are now available with 3 m axles)		17–25 ^d 5 ^d
Lower-power tractor for hauling drill		20
Labour		15
		20
Variable costs:		10
Seed		
Fuel	3/ha	7.5
Wearing parts – soil-engaging elements		
Chemicals		
Wheel-way maintenance		
Crop yield		

^aAdditional cost to the ± 25 cm system, i.e. total cost would be $6400 + 2400 = \text{US}\$8800$.

^bAdditional cost to the ± 3 cm system, i.e. total cost would be $8800 + 15,400 = \text{US}\$24,200$.

^cThis option has an annual US\$1330 correction signal fee.

^dTractor power or labour reduction, not both – see ‘Fixed and variable costs’ in main text.

- c. differential global positioning systems using satellites;
 - d. automatic steering controlled by the guidance system.
- 3.** CTF should liberate the full potential of no-tillage seeding by avoiding soil compaction damage in the cropping zone. This is likely to result in:
- a. improved crop yields from the outset;
 - b. better nutrient use efficiency achieved through greater root proliferation;
 - c. improved soil porosity, which provides better water infiltration, drainage and gaseous exchange;
 - d. reduced threat of denitrification, particularly in the presence of organic residues;
 - e. lower draught forces and wear on seed openers;
 - f. reduced labour and fuel inputs, particularly during seeding operations;
 - g. lower power demand for drilling, allowing a smaller tractor to be used for a given output;
 - h. more reliable and consistent operation of seed openers in a wider range of conditions and soils;
 - i. the potential for a wider range of crops to be grown with no-tillage.
- 4.** In other situations, many of these advantages will come from the change to no-tillage, which reduces, but seldom eliminates, the additional gains to be had from CTF. In most cases, combining CTF and no-tillage achieves a greater potential from no-tillage [Eds].

- 5.** CTF allows farmers to anticipate greater levels of precision in all operations so that they may:
 - a. increase the flexibility and effectiveness of weed control;
 - b. spray the crop row and inter-row independently;
 - c. use non-selective chemicals in the inter-row;
 - d. perhaps position and manage residues to allow their manipulation to greater benefit.
- 6.** The cost of converting to CTF need not be great, providing it is carefully designed and part of the forward-planning process. If properly planned, the benefits are likely to far outweigh the costs.
- 7.** There are a number of ways that CTF can be achieved and all will vary in terms of cost. Field layout is a particularly important aspect because it needs to account for field drainage, slope, operating efficiency and permanent obstacles.
- 8.** Permanent wheel tracks within a CTF regime need to be managed to ensure optimum performance. Management is likely to include:
 - a. regular infilling, preferably as an integral part of normal field operations;
 - b. engineering their drainage down slopes and in low areas;
 - c. sowing with crop in particular circumstances and in a particular way.
- 9.** Additional environmental benefits can be achieved by no-tillage in combination with CTF.