The Worshipful Company of Farmers

Potential of “No-till” Systems for Arable Farming

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Oxford English Dictionary – definition of "no-till"

"Designating a method of planting in which soil is not tilled but instead is planted by insertion of seeds in small slits, weeds being controlled by other means."

"Agricultural crops are far more sensitive to weeds than to tilth."

E. W. Russell, 1945. Rothamsted

Executive Summary

This report assesses the potential for "no-till" arable systems in the UK, by reviewing the national and international literature, and consulting with a number of UK farmers who have switched to "no-till" practices. Soane et al., (2012) in reviewing some 190 papers succinctly lists the advantages and disadvantages of "no-till". This work and the other material reviewed, plus the farmer feed back show evidence on the benefits of higher work rates, lower costs, greater soil bearing capacity and lower greenhouse gas emissions (GHG). The main challenges lie in the establishment of the crop, especially in wet conditions with crop residues present and in grass weed control; with worries particularly concerning blackgrass in the absence of new herbicide chemistry for the foreseeable future (>10 years) and the development of glyphosate resistance. Currently alternative tillage practices and delayed crop establishment appear to be the most promising method to assist with these emerging weed control issues. The concept of alternative tillage practices runs counter to the development of improvements in soil structure from a series of years of no-till, it is therefore imperative that further research be conducted to solve this issue.

Success depends upon good overall husbandry by ensuring soils are well drained and the problems of both deep and shallow soil compaction being removed. The move towards controlled traffic farming (CTF) and also lower ground pressure vehicle systems have much to offer in this regard. CTF may also be part of a solution to the frequently observed reduction in crop yield in the early years of switching to "no-till", alongside improved techniques for residue management.

As a result of the study the following research possibilities should be considered: -

1. Comparison of drill types in different soil conditions, especially wet soils with high residue loads. Further development of novel coulters/openers if required to help maintain seed depth and apply a "combined" application of fertilizer.
2. Continuation and extension over a wider range of soils and crops of the long term Tillage x Traffic study at Harper Adams University.
3. Management of grass weeds in "no-till" systems and the possible use of stale seedbeds and alternative tillage practices carefully targeted within the rotation.
4. Development of alternative herbicides and methods following the concerns over glyphosate resistance.
5. Catchment scale studies on the effects of "no-till" and other improved soil management practices on runoff and flood control.
6. The improved control of slugs and snails.

To which should be added further practical training programmes to assist farmers in the adoption of the techniques and the promotion of good drainage to reduce surplus moisture levels during the drilling operation and to assist in the control of blackgrass. Alternative break crops and cover/companion crops should also be investigated.

In conclusion "no-till" practices can offer significant potential operational, economic, soil and environmental benefits for the UK; these however come with a number of challenges for improved management many of which are being successfully addressed by current practitioners. Further research and development, however, is required to address the control of grass weeds, slugs and snails, and to further improve the operation of equipment in wet soils with high residue loads.

1. Introduction.

1.1. Background.

Traditionally tillage is used for crop establishment in order to loosen and aerate the soil for planting, incorporate crop residues and nutrients, mechanically destroy weeds and when carried out in autumn/winter expose the soil to frost in order to benefit soil structure. Nevertheless tillage has a high energy cost, it increases the loss of soil nutrients through leaching, reduces soil organic matter, microbes and earthworms, decreases water storage in the soil and can lead to increased soil erosion and emissions of nitrous oxide.

Minimum tillage (min-till) has been widely adopted in the UK and this has addressed many of the negative aspects of conventional tillage systems. However a significant further development in many countries including the USA, Australia and Brazil in recent years has been in “no-till” or “zero-tillage” systems. Over one third of USA crop land across 8 major crops had “no till” operations in 2009, and although ‘direct drilling’ of crops was practised in the UK in the 1970’s, the new approaches of “no-till” systems including alternative types of equipment have so far been practiced by a relatively few enthusiastic farmers.

“No-till” has the potential to address the economic and environmental interacting challenges of sustainable intensification, namely to reduce costs of labour, fuel and machinery, to reduce green house gas (GHG) emissions, and to increase carbon sequestration. This potential needs to be assessed in order to clarify the way forward for arable farming.

1.2. Objectives.

The study will assess the potential for no-till arable systems in the UK. It will review the global literature for the impacts of no-till arable systems for different soil types and rainfall levels and for different crops in terms of - crop yield, nutrient losses and fertiliser requirements, mechanisation requirements, crop rotations, soil organic matter, soil water retention and GHG emissions. It will also use UK farm case studies where “no-till” systems have been adopted. It will also reflect on recent results where controlled traffic farming is being practiced and identify gaps in knowledge where further research is required.

1.3. Aims of “no-till” Systems

According to a report in “The Independent” (07/08/2007) the main reasons for farmer’s to consider reduced tillage are: -

- To reduce energy consumption
- To reduce labour costs
- To conserve moisture
- To retain plant cover to reduce erosion

To which should also be added

- To minimise the loss of organic matter.

Each point is very appealing to the farmer who wants to make best profit margins in terms of field efficiency, fuel economy and work rate. The practice is also appealing to the farmer who wants to look after the land. However, these practices are most affected by poor weather conditions, as drier conditions are essential for sowing in order to avoid compaction and smearing in the final seedbed. They went on to say, “For anyone new to reduced tillage – one of the best tools in your tool box for reduced tillage is patience”. The best advice is to wait until conditions are excellent for sowing. There is little point in sowing a crop (especially winter barley) into a compacted or smeared seedbed. However, under wet autumn conditions this is a major challenge. As a result there is a need for improved management skills, a point highlighted in the farm case studies (especially Appendix 3)

2. Review of “no-till” Arable Systems.

2.1 Background.

The data in Figure 1 shows the trend in tillage practices in England from 1980 to 2010, it shows how reduced tillage declined and conventional plough based tillage increased in the 1980’s following the straw-burning ban. Reduced tillage has now risen to circa 40% of the total area. After a period of absence for nearly 25 years the area of direct drilling is now measurable at slightly less than 5%. The data does not specifically differentiate between no-tillage and direct drilling. This is in contrast to the proportion of growers using at least some “no-till” in Australia, which is now peaking at levels of around 90 per cent in many regions (Llewellyn and D’Emden, 2010).

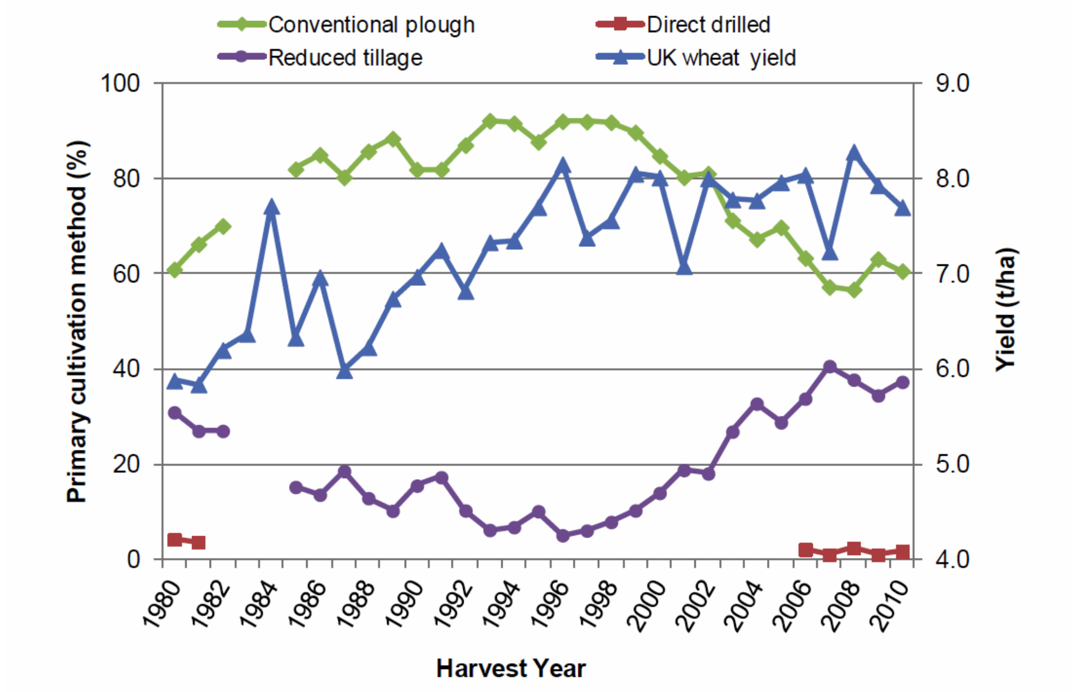


Figure 1. Proportion of winter wheat area established using various establishment methods in England from 1980 to 2010. After: Knight et al., 2012.

It is not the intention in this report to specifically debate the finer points of difference between direct drilling and “no-till”, see Table 1, other that to state that some authors and farmers consider the two terms to be mutually interchangeable (Baker et al., 1996) referring to “direct drilling” to be an English term and “no-till” as North American. Some, however, prefer to have a stricter definition where direct drilling may cause more soil disturbance at the time of seed placement and “no-till” attempts to just provide a slot for the seed to be placed in the soil. Focusing on “no-till” at the expense of direct drilling would also significantly reduce the extent of the available research data, which is valuable in addressing issues mutually relevant for both techniques. Strip tillage, a direct drilling system where disturbance of less than one third of the total field is cultivated (Reeder, 2000) is outside the remit of this report. For a recent review of the topic in the UK readers are referred to Morris (2014) that focuses on the technique for sugar beet production, the aim of which is to produce a narrow, residue-free cultivated zone that is suitable for drilling crops whilst leaving a significant area uncultivated.

Table 1. Tillage systems and their primary aims

Tillage system	Primary aim
Conventional: plough + secondary tillage	Deep overall soil disturbance, with inversion to bury residues and weeds – 200 to 250mm
Deep	Deep overall soil disturbance – 200 to 250mm
Shallow	Shallow overall soil disturbance – 75 to 125mm
Minimum	Shallow overall soil disturbance – 75 to 125mm
Direct drill	Plant seed directly into soil with localised soil loosening
“No-till”	Plant seed directly into soil with minimum soil loosening
Strip tillage	Localised soil disturbance less than 1/3 of field area.

The opportunity for “direct drilling” and “no-till” to be seriously considered was as a result of improved herbicides such as paraquat that could control weeds. Imperial Chemical Industries developed these in the 1960’s and research was undertaken in the UK in the 1970’s to pioneer these techniques. This work primarily focused at the Letcombe Laboratories in Berkshire, was not as successful as expected, due to the reasons listed below; however, there was a still a small amount of residual activity prior to the introduction of the straw burning ban as shown in Figure 1.

The reasons for the lack of adoption of “direct drilling” systems were: -

1. Poor germination in wet, anaerobic conditions, which caused greater risk of seedling losses from the toxic effects of decomposing straw residues in the seed slot (Lynch, 1977).
2. Poor weed control (Morris et al., 2014).
3. High residue levels of relatively “green” non-weathered straw as a result of the introduction of the “straw burning” ban.
4. Poor straw chopping and spreading of residues.
5. Poorly structured sandy soils and disc/tine smearing in poorly drained clay soils.
6. Commercially available equipment not fully optimised to handle (1 - 6) above.
7. Higher slug populations.

These disadvantages were recently reported in the paper by Soane et al. (2012) and are given in Table 2 alongside the key advantages. This table was also published by HGCA (2012) as an Information Sheet for their levy payers. Soane and his co-authors were extremely methodical in their analysis of European practices and concluded that “no-till” has a greater probability of success in drier conditions. They do report that the benefit of “no-till” in northern regions usually allows earlier drilling of winter-sown crops. However, due to lower soil temperatures and higher moisture contents in the spring, “no-till” can cause a delay in the drilling of spring-sown crops. They also comment on the fact that soils that are managed with “no-till” practices have higher soil bulk densities and bearing capacities than ploughed land, with a pronounced vertical orientation of macro-porosity allowing penetration of roots and water. Particular care must be taken at harvest to minimise soil damage and to ensure an even distribution of residues prior to drilling. Despite the many advantages of “no-till” which are numerous, many studies (e.g., Morris et al., 2014 for East Anglian conditions) indicate that the crop yield immediately after adopting “no-till” are lower than ploughing, but that they improve with time as illustrated in Figure 2. Christian and Ball (1994) demonstrated that the yields of winter barley in the first year of “no-till” were 90% of those after 17 years of no-till in the same season.

Table 2. Relative agronomic advantages and disadvantages of no-tillage systems.
After: Soane et al., 2012.

Advantages	**Disadvantages**
Lack of compaction below plough furrow	Crop establishment problems during very wet or very dry spells
High work rates and area capability	Weed control problems
Increase bearing capacity and trafficability	Cost of herbicides, herbicide resistance
Reduced erosion, runoff and loss of particulate P	Risk of increased N_2O emissions and increased dissolved reactive P leaching
Opportunities to increase area of autumn sown crops	Reduced reliability of crop yields
Stones not brought to the surface	Unsuited to poorly structured sandy soils
Reduced overall costs (fuel and machinery)	Unsuited to poorly drained soils
	Risk of topsoil compaction
	Increased slug damage

The reasons for the initial poorer performance were stated as: -

1. Compaction from the previous harvest traffic before soil strength and bearing capacity had increased.
2. Limited time for the build-up of soil structure.
3. Reduced nitrogen availability.
4. Lack of experience with managing no-till.

Despite these issues Figure 2 shows that the total cost of production per hectare falls from the outset, as do tractor hours: whilst soil structure and earth worm population increase. Initially fertilizer and pest protection requirements increase in the first year and then decrease, as do the costs of equipment (plant ownership costs) as a result of the new capital investment – ultimately the equipment costs fall. This later point is reported in the farm case studies, see Chapter 3 and Appendices.

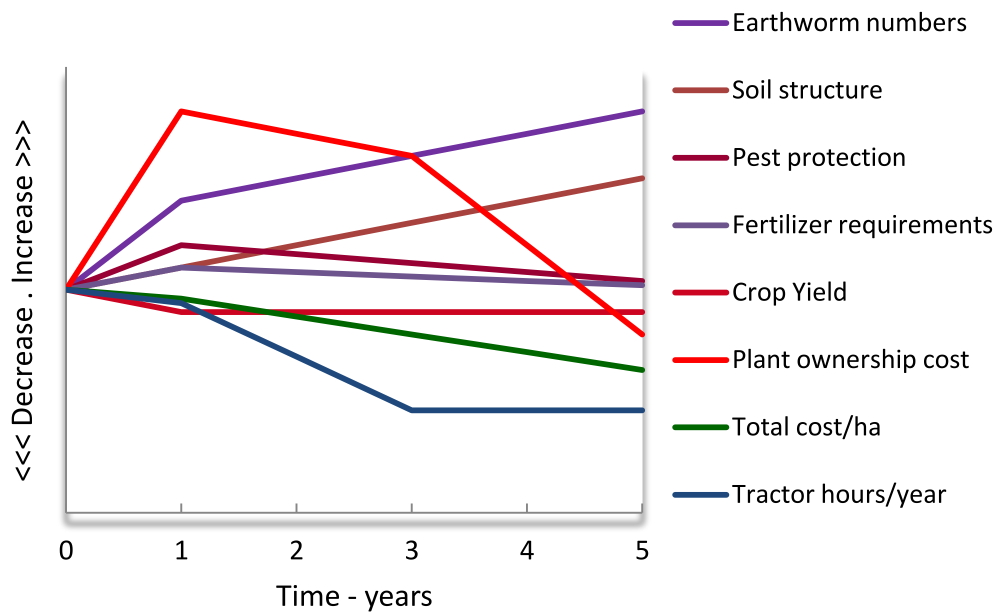


Figure. 2. Likely short – and long-term trends, which might arise as a result of converting from tillage to no-tillage. After: Carter, 1994.

2.2. Soil Classification.

The issues relating to soil physical conditions were reviewed by Cannell et al., (1978) in a provisional classification of the suitability for direct drilling. The authors recognised the limitations in the evidence that it originated from the results of field experiments over a limited time period with systems that used equipment that may not have been optimised for the demands of UK soils. The counter argument was that the classification was based on approximately 50 field sites giving 214 site years of data. A resource that is difficult to imagine in todays research environment. Figure 3 shows their "provisional" classification soil suitability for direct drilling of combinable crops for England, Scotland and Wales, it had 3 main categories, where: -

1. Yields similar to those from conventional cultivated crops could be expected from both autumn and spring grown cereals. The group included chalk and limestone soils, and well-drained loamy soils – occupying about 30% of the cereal growing areas of the country.
2. With good management yields of winter cereals were likely to be similar to conventional cultivation, but yields of spring cereals were likely to be lower. The category included calcareous clays and clayey or loamy over clay soils which have been improved by drainage – occupying about 50% of the cereal growing areas of the country but was largely confined to England.
3. Compared with conventional cultivation there was a substantial risk of lower yields, especially with spring-sown cereals. This group included sandy soils with low organic matter content, silty soils, many wet alluvial soils and clayey soils – occupying about 20% of the cereal growing areas of the country.

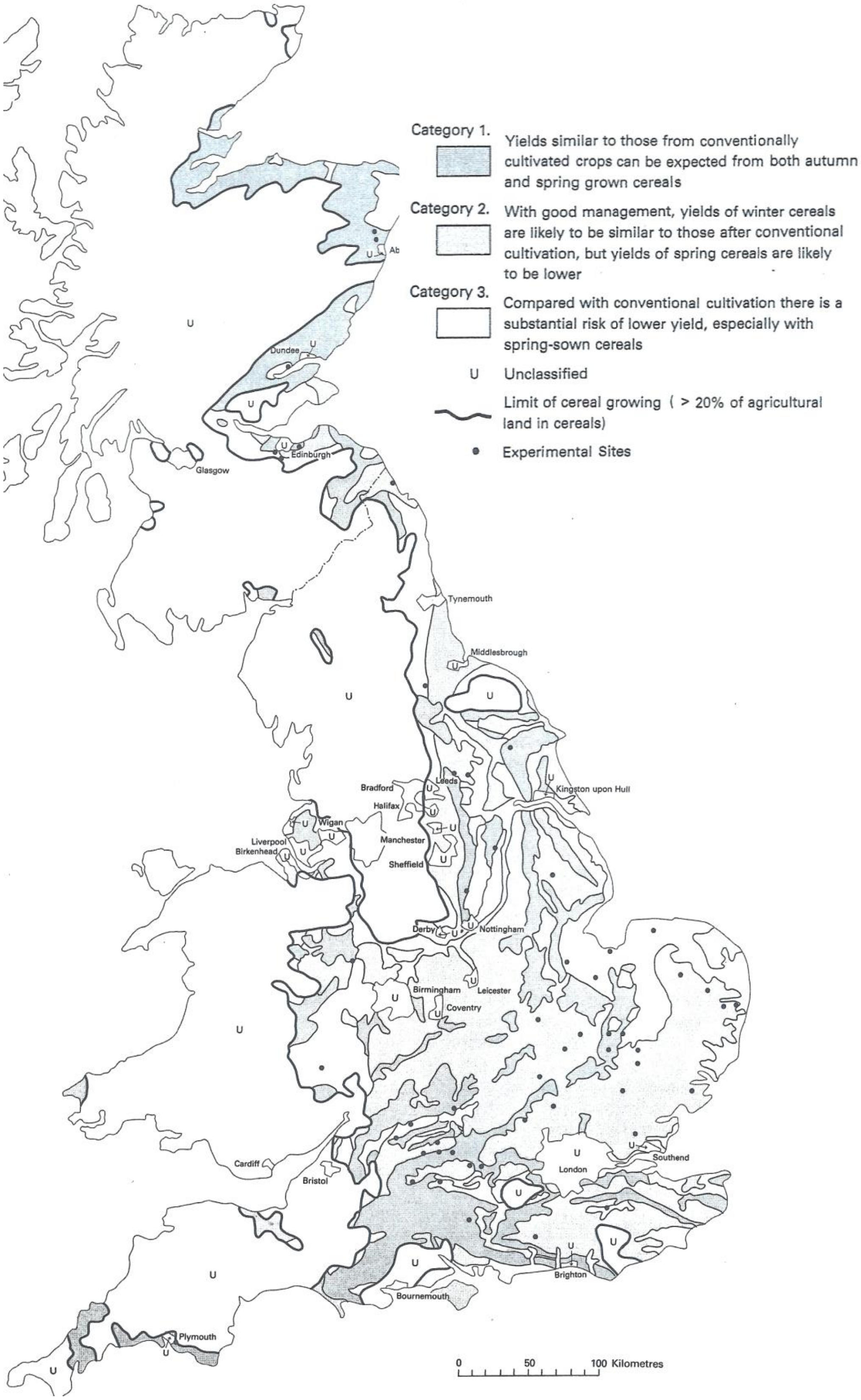


Figure 3. Provisional classification for soil suitability for direct drilling of combine harvested crops. After: Cannell et al., 1978.

Finney (2014) and Davies (2014) report that they together with Pidgeon and Cannell had attempted to update the “provisional” classification as the previous publication is not easy to access and the effect of recent developments in equipment and management should be included. Their draft manuscript, regrettably not published, concluded that after reviewing the work of Soane (2012) and Cannell (1985) that the English cereal growing areas lie at the boundary between two European agro-climatic regions: -

1. The southern and eastern areas, which are drier and warmer and direct drilling has shown equal or better yields than conventional tillage where the barriers to adoption are non-technical, and
2. The northern and western areas, where technical problems of compaction, straw management, reduced soil temperatures and wetter conditions prevent successful direct drilling.

As a result identifying soil suitability in the UK is vital and the full potential may not be realised until improved traffic management systems are adopted, at a stage where the influence of soil type may be much less significant.

They also reported that in 1978 when the first report was published the control of blackgrass and other grass species was a major problem of non-ploughing systems. Since which time a number of graminicides have lost effectiveness due to resistance and that the current position is not dissimilar to the situation in 1978. One solution practiced by some innovative farmers is to control blackgrass using a 2 cm deep stale seedbed with controlled traffic farming systems. This, however, requires very smooth fields and contour hugging equipment.

2.3. Environmental Aspects.

Recent work using non-destructive 3D imaging of soil by X-ray computed tomography at Sutton Bonnington by Mooney and his colleagues (Mangalassery et al., 2014) have helped explain the potential benefits to the soil structure and the reduction in greenhouse gas emissions from no-till, as shown in Figure 4. Their studies took place on 22 farms in the East Midlands with a range of soil textures where the soils managed under “no-till” practices had a higher bulk density, soil shear strength and moisture content. The X-ray CT measured porosity was higher in the tilled soils, as was pore size and the surface area of the soil pore system. The “no-till” managed soils contained higher levels of soil organic matter and more microbial biomass. These factors influenced the potential carbon dioxide (CO_2) flux and the potential methane (CH_4) flux, which were both higher in the tilled soils. In contrast the nitrous oxide (N_2O) were higher from the “no-till” managed soils. As a result the net global warming potential was significantly higher, by 31% on an area basis and 26% on a weight basis, from tilled than the “no-till” managed soils. The work indicates that “no-till” practices could play a significant part in reducing greenhouse gas emissions and contribute to the efforts to mitigate climate change. The results also showed that the length of the period under “no-till” management (between 5 and 10-years) did not significantly effect the net emissions of greenhouse gases from the non-tilled soils.

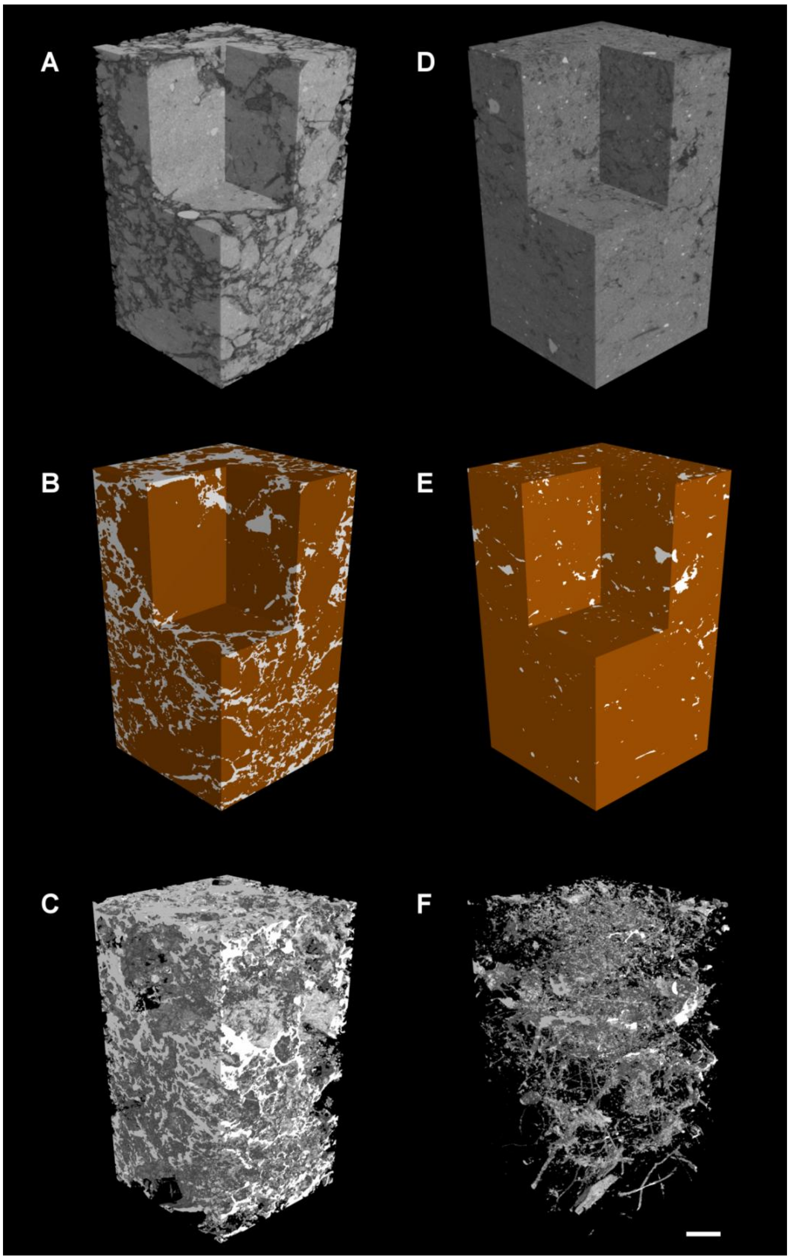


Figure 4. Non-destructive 3-D imaging of soil by X-ray CT. Tilled (A-C) and "No-till" (D-F) soils. After: Mangalassery et al., 2014.

A & D: 3D rendered grayscale density map of soil cores showing a virtual 'cut-out' to reveal differences in soil structure. B & E: Threshold 3D image highlighting 'solid' soil in brown and 'pore' space in white. C & F: Visualisation of pore space only highlighting high connectivity of pores in the tilled soils and the presence of numerous bio-pores in the tilled soil. Scale bar = 1cm.

In addition to the positive environmental issues raised above, Holland (2003) reviewed a number of studies from primarily outside Europe to show "considerable evidence" that conservation tillage (effectively "no-till") can provide a wide range of benefits to the environment and wildlife. Stating that this is most beneficial when the practice is adopted across a large proportion of the cultivated land. Catchment scale projects are rare; however, one in the USA showed a 64% reduction in runoff and a 99% reduction in sediment losses from the use of conservation tillage across a catchment. A further study around Lake Erie showed a beneficial effect on aquatic pollution by reducing eutrophication.

2.4. Seed Coulter/Opener Design.

In addition to the problems reported in the UK there is considerable evidence from around the world that seeds which have been forced into close proximity to straw can suffer from fungal phytotoxicity problems with some seed drills, when the surface is wet (Morris et al., 2010). The probability is that the drills were equipped with disc type coulters similar to that shown in Figure 5, which through their geometry will force the straw residues down into the coulter slot, a problem often referred to as “hair pinning” as shown in Figure 6. Traditionally the disc coulters were used for drilling into tilled soil and consisted of a pair or even three discs. In contrast tine coulters similar to those in Figures 7 and 8 tend to lift both the soil and the crop residues leaving the slot relatively clear of entrapped straw. With rake angles (the angle of the tine face to the direction of travel) similar to those shown the tines will not unduly disturb the soil and have a relatively low draught force. The author when designing grassland injector tines for anhydrous ammonia in the 1970’s used similar geometries following a detailed study into the mechanics of very narrow tines (Godwin and Spoor, 1977). Figure 7 also shows the wing attachments that help to position the seed a small distance from entrapped straw.

Figure 5. An early double disc type coulter. (Courtesy: Spoor)

Figure 6. Smeared slot (upper) and straw trapped in coulter slots (lower). (Courtesy: Spoor)

In an attempt to overcome some of the issues with the early variety of disc coulters Baker et al. (1979) working in New Zealand designed a “Cross slot” opener that consisted of a disc and an associated winged tine (inverted T share) that placed the seed on the “bench” created by the wing a short distance shallower than the depth of the disc, Figure 9. The effect of this arrangement is illustrated in Figures 10 (a and b). Earl and Spoor (1994) compared the performance of this device in four clay sites in the UK alongside that of the Moore “Uni-drill”. The “Cross slot” design had some problems in wet conditions, which were corrected by modifications to the press wheels and their scrapers. The “Uni-drill” was also modified to place the seed above the depth of the disc coulter, as shown in Figures 10 (c, d and e) and 11. As a result relatively good performance was achieved provided that the criteria given in Table 3 was satisfied (Earl, 1994). These criteria still hold today, together with the recommendations given by Ashworth et al., (2010) for the operation of “no-till” drills in “sticky” Australian soil conditions in Table 4.

Desboilles (2008) continued with the development of the dual depth approach by the adoption of a bent leg tine (similar to a shallow Paraplow) with a secondary trailing tine to operate at drilling depths giving a soil disturbance profile as shown in Figure 12.

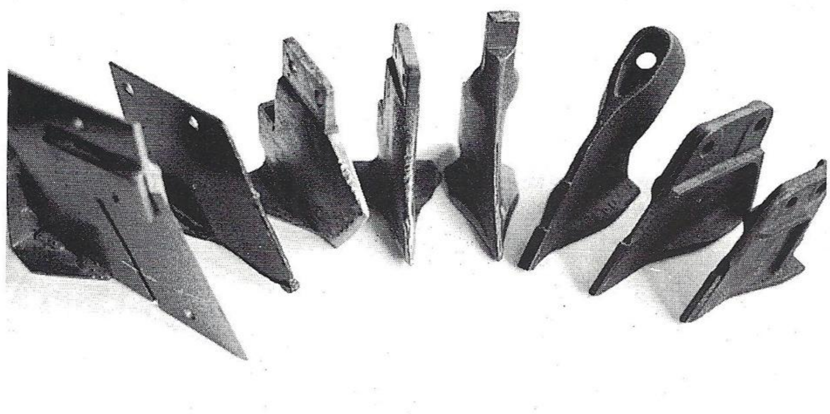


Figure 7. A number of versions of the 'Baker Boot' inverted T-shaped no-till tines (openers). After: Baker et al., 1996.

Figure 8. 'Seed Hawk' tine. (Courtesy: Vaderstad)

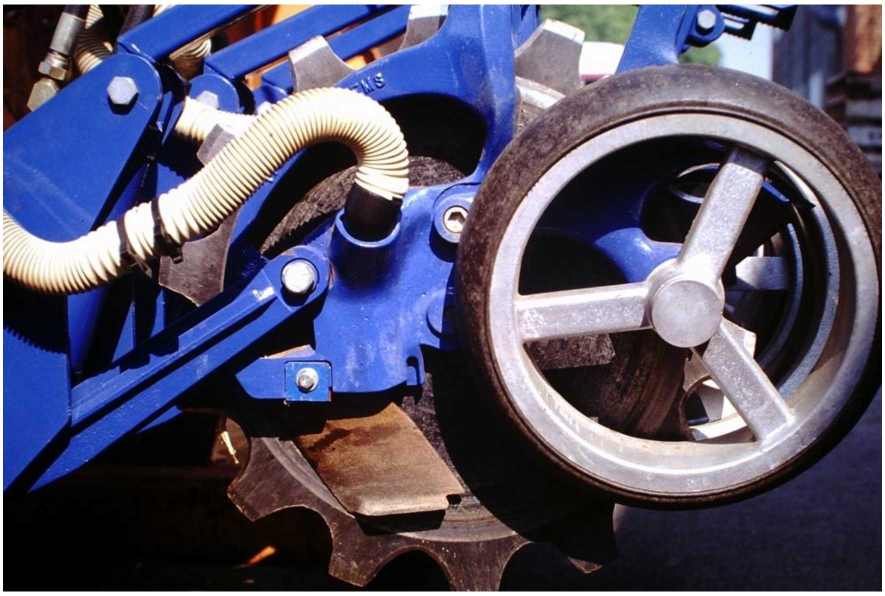


Figure 9. 'Cross slot' disc-coulter arrangement. Showing inverted T share. (Courtesy: Spoor)

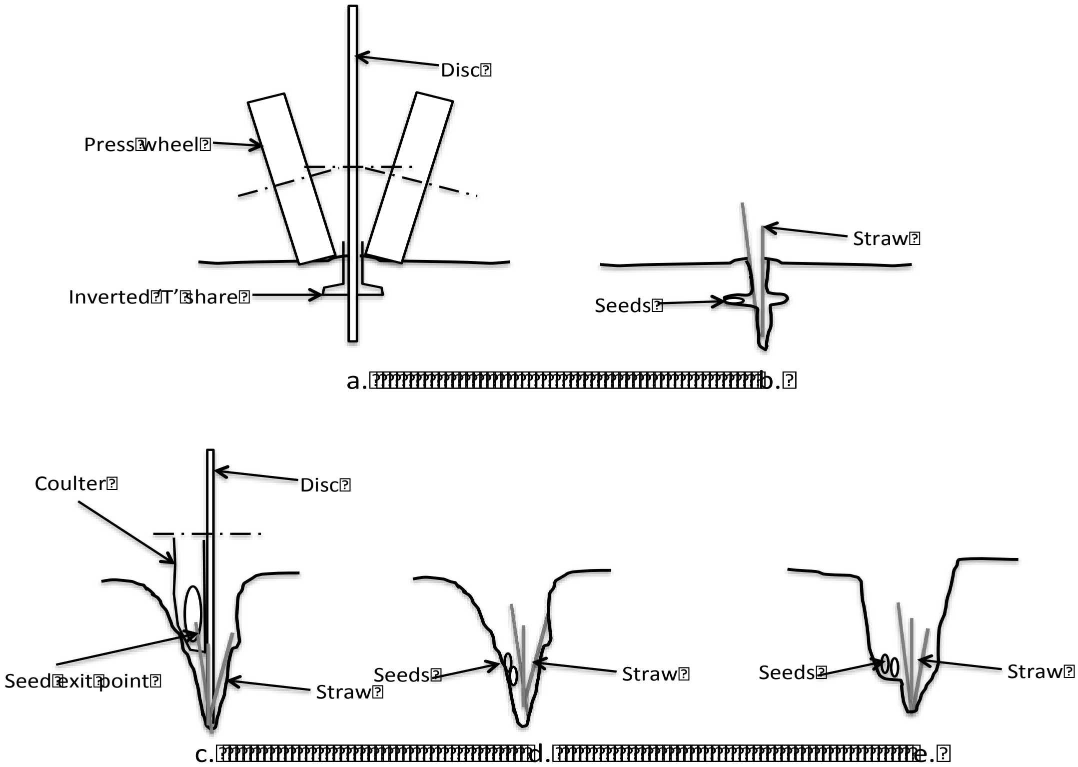


Figure 10. Soil-seed –slot profiles of the 'Cross-slot' and 'Uni-drill' openers. Redrawn from Earl and Spoor, 1994.

a.'Cross slot' seed placement mechanism. b. Location of seed relative to the straw. c. 'Uni-drill' seed placement mechanism. d. Un-modified seed position. e. Modified seed position.

Figure 11. Modified Moore 'Unidrill'. Showing seed placement coulter. (Courtesy: Spoor)

Table 3. Criteria for improved direct drilling. After: Earl and Spoor, 1994.

Dry conditions	Wet conditions
Good penetration	Reduce smear in the coulter area
Minimum straw to discourage pigeons*	Enhance drainage
Leave stubble to discourage pigeons*	Avoid seed-straw contact
Maximise moisture conservation through efficient slot closure	Minimise surface straw cover to reduce risk of frost heave**

*A particular problem in this study

**To permit more surface drying and surface weathering to create a more crumb like surface structure, which would be less prone to serious frost heave.

Table 4. Recommendations for the operation of direct drills in sticky soil conditions. After: Ashworth et al., 2010.

1.	Fit high capacity scrapers on disc, press and gauge wheels.
2.	Experiment with high flex pneumatic gauge wheels and large gap settings.
3.	Move the gauge wheel away from the disc to remove the gauge wheel surcharging effect.
4.	Use V-twin press wheels in clay soil conditions*.
5.	Minimise frictional losses, as the disc drive is less reliable in soft sticky soils.
6.	Operate at shallower depths to reduce contact with deeper wetter soil (in a drying profile).
7.	Operate at faster speed to generate sufficient momentum to promote self-cleaning effects.
8.	Wait for the topsoil to dry sufficiently (forming a dry crust) before seeding.
9.	Minimise the mixing of residue with sticky soils, such as inter-row sowing** into standing stubble and seeding over a dry surface crust.

* Also consider spacing the twin press wheels in a staggered format to eliminate soil and residues being gripped between adjacent press wheels and the need for extra scraping action. Wright (2014).

** Aided by the application of real time kinematic (RTK) satellite navigation systems.

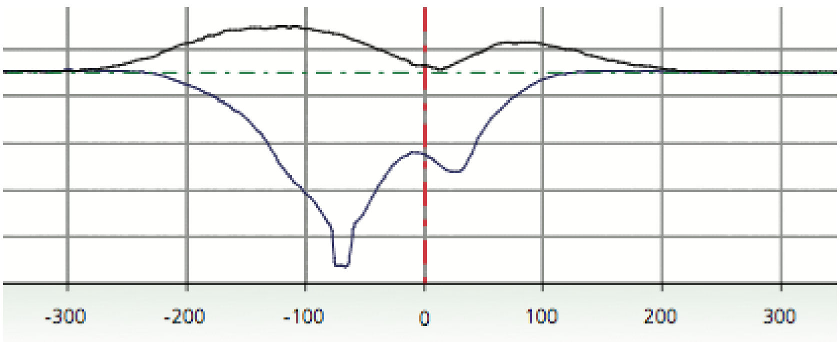


Figure 12. Soil disturbance profile from prototype seeder tine. After Desbiolles, 2008.

Currently both disc and tine drills are sold in the UK market dependant upon the prevailing soil conditions and tillage requirements, with a number of companies marketing both, see Chapter 4. The farmers that reported on their "no-till" farming experience in the Appendices have not commented unfavourably about the performance on the coulter/openers that they have used.

Despite relatively few significant design changes, many attribute the reason for the change in performance from the 1970's to: -

1. Improved chopping and spreading of straw by the combine harvester.
2. Improved sweeping and chopping of residues by leading attachments (referred to as residue managers in Australia (Desbiolles, 2007)).
3. Improved seed placement relative to the disc and any trapped straw.
4. Improvement in weed management, e.g. barren brome (Morris et al., 2014).
5. Improved timeliness (Carter et al., 2003).

Unless the soil is very wet and has a low resistance to the action of the disc when "hair-pinning" can still be problematic, see the Farm Case Studies in the Appendices. Table 5 lists some of the tactics used in drier Australian conditions to minimise residue pinning.

Table 5. Minimising residue pinning. Tactics used by Australian farmers. After: Desbiolles, 2007 & 2008.

Stubble treatments	**Machine set up and operation**
Leaving stubble standing	Adapt residue managers
Uniform spreading of straw at harvest	Re-sharpen discs*
Seeding when stubble is dry	Optimize leading coulter type and disc settings
	Use heavier duty discs

*Plus maintaining chopper knives. Wright (2014).

The tine drill shown in Figure 8 initially developed in Canada has gained in popularity in many applications around the world and was initially introduced to the UK in the equipment manufactured by John Dale and is now marketed by Vaderstad. This system has tines (knives) for placing fertilizer alongside and deeper than the seed, hence saving additional field operations especially for spring sown crops and autumn sown oil seed rape.

2.5. Draught Forces and Energy Requirements.

Tillage draught forces and fuel consumption data from the Traffic x Tillage study at Harper Adams University (Arslan et al., 2014, see also Chapter 5) are given in Table 6. The data was collected for 4m wide multi-tine/disc/packer tillage tool (Vaderstad: Topdown) operating at 250 and 100mm deep and a disc type seed drill (Vaderstad: Spirit) for both tilled and no-till plots; a 260hp rubber tracked tractor drew the equipment at 8km/h. This clearly shows the 60% and 47% reduction in fuel use for "no-till" in comparison to deep and shallow tillage respectively.

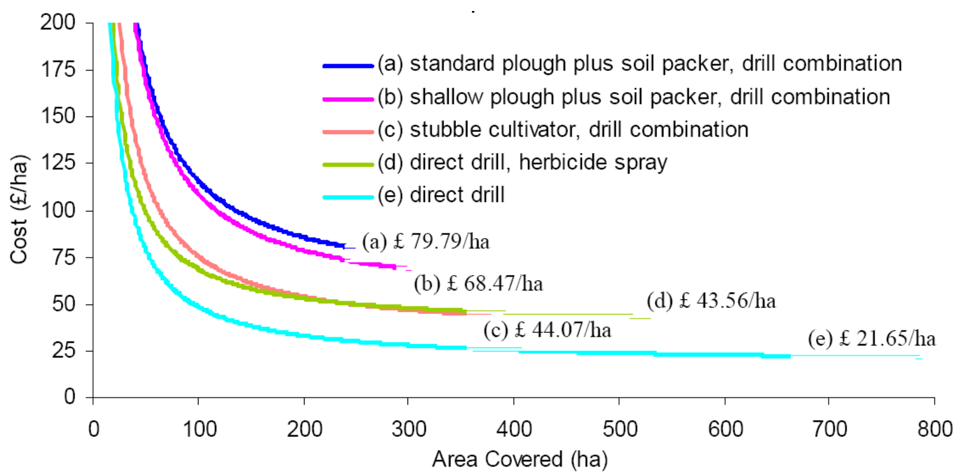
Table 6. Draught force and fuel consumption for 3 tillage /drilling systems. After: Arslan et al., 2014.

Treatment	**Tillage draught force, kN**	**Drilling draught force, kN**	**Fuel consumption for Tillage + Drilling, l/ha**
Deep Tillage - 250mm	64.9	15.9	22.16
Shallow Tillage -100mm	21.3	16.7	16.42
No-till	0	16.5	8.82

2.6. Economics.

One of the key drivers for no-till/direct drilling is the reduction in energy for cultivation and hence much wider equipment can be used and at faster speeds*. This means that establishment rates of as high as 1ha/h/metre width (Vaderstad, 2013) are achievable – significantly increasing the area of crop that can be planted in a season and reducing the cost/ha. The results of a cost-modelling exercise by Vozka (2007) given in Figure 13 for both a 135hp (102kW) and a 300hp (224kW) tractor matched to the appropriate sizes of tillage tools, show that the direct drill system could potentially have a work rate 2.5 x that of a conventional plough, packer, drill combination at about one quarter of the cost when farming a sufficiently large area and the cost becomes almost insensitive to the area covered. These figures are not dissimilar to those reported in the Farm Case Studies given in the Appendix. Vozka also undertook the cost models for a 220hp tractor and the results showed little difference (+/- £2/ha) in the cost/ha for the maximum area covered for each size of system. As expected the area covered is proportional to the tractor size.

*N.B. Care should be taken when operating tine drills to avoid excessive soil throw.



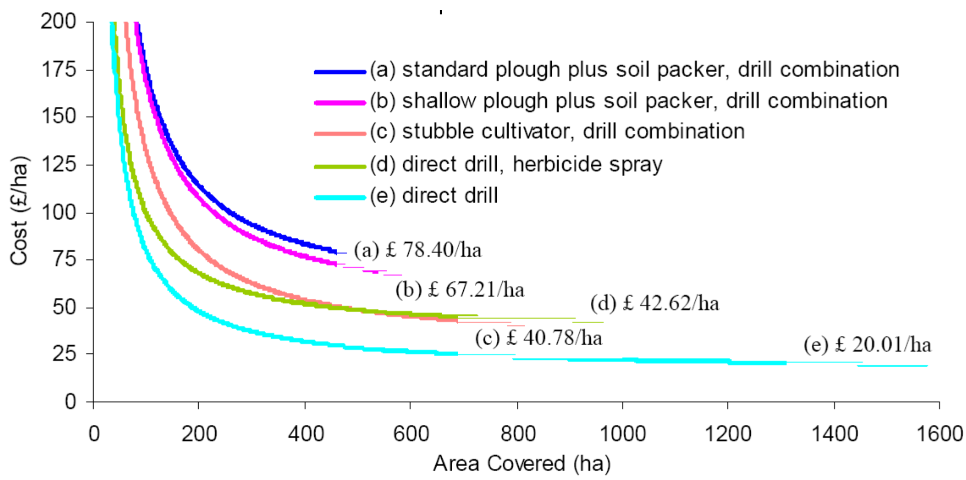


Figure 13. Comparative cost/ha of a range of tillage practices based on 135hp (upper) and 300hp (lower) tractors with matching equipment. After: Vozka, 2007.

2.7. Weed Control.

Russell (1945) concludes from a Rothamsted study on cultivation systems: “that agricultural crops are far more sensitive to weeds than to tilth”, unfortunately the HGCA (2012) report that “no-till” systems tend to increase grass weeds and volunteer cereals as their seeds are retained nearer to the surface where they readily germinate. This is a serious problem for the control of blackgrass and sterile brome and perennial grass weeds such as couch grass. Soane et al. (2012) reported that herbicide use should be kept to a minimum consistent with the desired level of weed control and that the weed bank may be controlled by the use of a chaff catcher on the combine harvester and occasional remedial tillage operations. The most widely used herbicide in “no–till” systems, glyphosate, fortunately has low eco-toxicity and is strongly absorbed on contact with the soil and hence does not cause a large environmental risk. However, there is evidence of increasing levels of glyphosate resistance in both Australia and the USA with “no-till” systems (HGCA, 2012).

The results of the first year of a five-year study on the effects of remedial tillage to control blackgrass is currently being studied in the UK by Agrii and Lemken (2013) are given in Figure 14. This shows that periodic mouldboard ploughing can have a major effect in controlling blackgrass. They report that the difference between early direct drilling and improved blackgrass control through ploughing of 194 ears/m^2 is very significant when 100 blackgrass ears can decrease yield by 1 tonne/ha.

Their key conclusions are: -

1. A season of ploughing in the tillage rotation can reduce blackgrass numbers.
2. Use good ploughing techniques and bury the weed seeds.
3. Do not plough in the second year as this brings blackgrass seeds back to the surface.
4. Good ploughing followed by 2 years of direct drilling has reduced blackgrass and increased yields.
5. Continual direct drilling or shallow tillage allows blackgrass numbers to increase. These systems only work well if a stale seedbed is achieved first and the herbicide chemistry works well.
6. With resistance issues, cultivations are having a greater effect on blackgrass control than current pre and post emergence chemical options.

Their data also shows the benefit of direct drilling on 12th October as opposed to 25th September.

Hence, there is evidence that until the issues of weed control are resolved, that when moving towards a “no-till” system it might be prudent to keep a mouldboard plough in serviceable condition and hope that it will not be required! The inclusion of stale seedbeds in the rotation should be considered and good drainage is a prerequisite to ensure the soil environment is less hospitable to blackgrass. Rotational cropping including the establishment of spring crops is part of the armoury of cultural control methods that need to be considered.

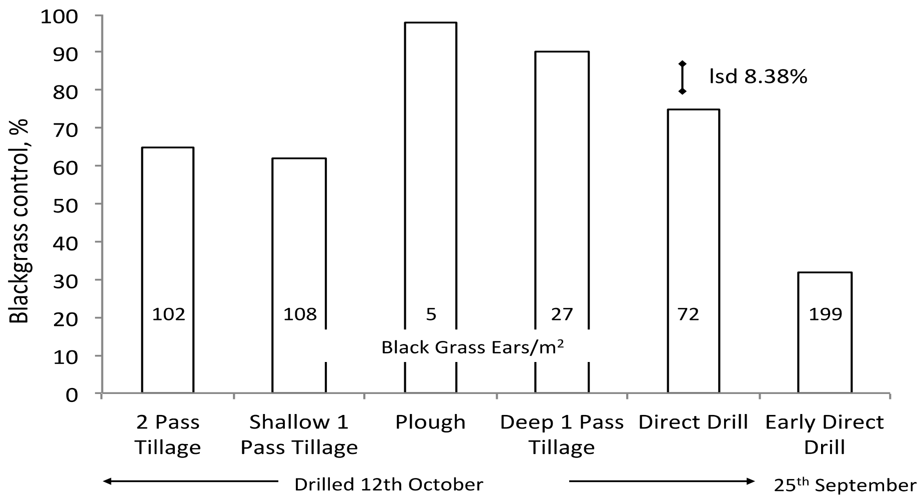


Figure 14. Effect of different tillage systems on blackgrass control. After: Agrii and Lemken, 2013.

3. Synopsis of "no-till" Farm Case Studies.

3.1. Introduction.

Five farms that currently practice no-till farming have willingly provided information in the form of a short questionnaire about their experiences. Each response is given in detail in the Appendices. This was never intended to be a statistically robust survey and it could be argued that it was biased from the outset, as the farms chosen were selected from a group of farmers that are currently at the leading edge of "no-till" practices in the UK. Their responses do however give a valuable guide to the reasons for embarking on the adoption of no-till, the problems they have had to overcome in doing so and the benefits they have found. The next sub-sections provide a synopsis of the responses.

3.2. Reasons for Starting "no-till" Farming Practices.

These were primarily to improve the economic performance of the farm together with improving the soil condition. The economic performance was driven by the need to reduce the cost of both equipment and time for crop establishment hence lowering the costs of production. Similarly the desire to improve soil conditions was driven by the need to improve soil structure by improving soil organic matter content which in turn would reduce wind and water erosion and improve soil fertility.

3.3. Benefits of Moving to "no-till" Farming.

The results here generally reflect the reasons for starting no-till farming, namely economic and soil structural condition, with added social benefits for the farmer having more time with his family and for the farm to become more economically secure.

Specifically the operational/economic benefits have been: -

1. Reduction in both fuel and labour.
2. Establishment cost savings.
3. Wider drilling window and improved timeliness.
4. Ease of matching equipment widths.
5. Improved trafficability.
6. The ability to drill straight into a cover crop.

Specifically the soil/environmental benefits have been: -

1. Increase in soil organic matter, soil organisms and invertebrate activity.
2. Improved soil structure, infiltration and drainage; together allowing for a better recovery from major weather events.
3. Increase in topsoil moisture in dry seasons.
4. Less soil splash and soil erosion.
5. More uniform germination across variable soil types.
6. Lower germination of weeds and a reduction in weed seed burden.
7. Increased wildlife.

3.4. Problems faced with Adoption of “no-till” Farming.

One farm reported “none!”
A compilation of the responses of the other farms is given below: -

1. Early compaction issues until the soil “stabilises”.
2. Slugs (after oil seed rape) and snails.
3. Residue management, soil cover in wet conditions.
4. Sourcing seed for low cost cover crops.
5. Grass weeds and the multiplication of weeds not controlled by glyphosate.
6. Addressing seasonal changes especially in the first five years.
7. Emergence issues and variation in drilling depth.
8. Nitrogen “lock-up”.
9. Complacency of manufacturers to improve equipment: drills, straw choppers and chaff spreaders. Adapting dry land machines to wetter conditions.
10. “Hair pinning” of straw residues when drilling.
11. Adapting to new agronomic practices and the re-training of agronomists and staff.
12. Controlling field traffic to help reduce compaction.
13. Peer pressure and public concerns about “untidy looking fields”.

3.5. Effects of Adopting “no-till” Farming on Crop Yields.

Generally these have been reported as very favourable, often no different to conventional tillage. Some are in accord with Carter (1994) and state a reduction in the first 2 to 3 years, with the yield returning to or exceeding those of previous tillage methods. The farmers agree that the weather condition during the season can make a difference, but state that this probably varies in line with the effects for other tillage practices, the challenges appear in wetter conditions.

All farms report that the system works best in dry conditions, with one making the statement that it is still the better "tillage" practice in all conditions and another that the last two years have provided a valuable learning experience. All farms are adopting "no-till" as a whole–farm technique and make the point that it is the long-term benefits of farming with undisturbed soils that is the key to success.

One farm has fully embraced controlled traffic farming (CTF) (see Chapter 5 for details of CTF) for a period of 5years and reports that this is essential for managing his clay soils and that equipment wear rates are reduced on sandy soils. Others are practicing improved traffic management and/or are watching the developments in CTF with interest.

3.6. Equipment and Time Requirements.

The farms report the use of 4 – 8m wide seed drills from a range of suppliers, namely: - Clayton, Great Plains, John Deere, Seed Hawk (Vaderstad) and Weaving (see Table 5, for further details + the details of other suppliers). One farm reports that the no-till drills require 20-25 tractor hp/metre. Others state that they operate with between 0.9hp/ha and 1.4hp/ha, with tractors in excess of 150hp. The larger horsepower provision may be explained by some of the farms operating as contracting businesses.

The time for crop establishment varies between 15 and 40mins/ha, with the average towards the lower figure and the higher time requirement on the clay soil. One farm reports that the work rate is approximately twice that of the previous min-till operations. All farms report a significant reduction in machinery costs from as much as £5000/year for a 375ha enterprise; another has not had to replace some "traditional" equipment for his contracting business. Whilst some farmers have retained their traditional equipment others have not.

3.7. Costs of Production

Generally input costs are reported as varying little from those of other tillage practices, with the exceptions listed below, namely: -

1. Fuel - Has typically been reduced to 35-50% of that for traditional tillage practices.
2. Fertilizer – Overall similar, with some increase earlier in the move to no-till, one farm reports a c.50% reduction in P and K.
3. Herbicides – Higher glyphosate usage, more stubble cleaning sprays - otherwise very similar with some reduced inputs. Black grass is reported as becoming less of a problem with time.
4. Pesticides - Overall similar, with a 25% increase in slug pellets in one case.

Overall the costs of production have fallen, with the actual amount dependant upon the previous tillage system. The reported figures are: -

1. £45-50/ha; £160-200/ha; £6.70/t less than min-till (c. £55/ha).
2. Cultivation and establishment costs reduced by 25% to 50%.

3.8 Overall comments.

The interesting result is the great similarity in the positive responses concerning “no-till” from farms ranging from Kent to Yorkshire, with soils ranging from gault clay to fen peats, with mean annual rainfalls from 600 to 800mm (with wide variation in recent years) and cropped areas from 400 to 1250ha. There is general agreement between the farm experience and that of the research literature concerning the practice in the UK. The farm experience is beneficial in highlighting the future requirements for research and development.

4. Suppliers of “No-till” and Direct Drilling Equipment

The responses in the Farm Case Studies in the Appendices indicate a range of possible drill suppliers. Table 7 gives further details of those currently providing equipment to the UK market. There is no intention in this table to differentiate between those that are better suited to “no-till” rather than “Direct Drilling” as local soil conditions and farmer experience will inevitably influence the choice, it is imperative that local knowledge/experience together with suppliers advice should be consulted prior to the final selection.

Table 7. Suppliers of No-till and Direct Drills

This list is aimed at helping the reader identify potential equipment, it is probably not exhaustive and the author apologises to any supplier he or his associates have failed to identify.

Manufacture	Website address	Models	Type of Drill
Amazone	www.amazone.net	Cayena/Condor/Primera	Tine
Bertini	www.bertini.com.ar/	10.000/22.000/30.000/ 32.000	Double disc
Claydon	www.claydondrills.com	Hybrid	Tine
Cross Slot	www. crossslot.com	Crossslot	Disc/Tine
John Dale	www.daledrills.com	Eco-Drill/ Mounted Tine Drill	Tine
John Deere	www.deere.co.uk	740A/750A	Single/Double disc
Great Plains	www.greatplainsmfg.co.uk	Centurion	Disc
Horsch	www.horsch2.com	Sprinter	Tine
Horsch	www.horsch2.com	Pronto	Disc
Kverneland	www.kvernelandgroup.com	Accord MSC	Disc
Lemken	www.lemken.com	Jantar/Saphire/Solitar	Double Disc
McConnel	www.mcconnel.com	Seedaerator	Tine
Mzuri	www.mzuri.eu	Pro-till	Tine
SimTech-Aitchison	www.simtech-aitchison.co.uk	T-SEM	Disc/Tine
Sumo	www.sumo1.com	Unidrill/Versadrill	Disc
Sumo	www.sumo1.com	DTS	Tine
Vaderstad	www.vaderstad.com/uk	Rapid	Single Disc
Vaderstad	www.vaderstad.com/uk	Spirit	Double Disc
Vaderstad	www.vaderstad.com/uk	Seed Hawk	Tine
Weaving	www.weavingmachinery.net	Big Disc/	Double Disc
Weaving	www.weavingmachinery.net	Sabre tine	Tine

5. Controlled Traffic Farming (CTF) and Low Ground Pressure (LGP) Systems and "no-till".

One of the farms surveyed reported that they had been operating with controlled traffic farming practices (CTF) for 5 years and others were leaning towards the philosophy of reduced traffic intensity. CTF is where field operations are focused on predetermined traffic lanes and equipment widths and wheel track spacing's are matched (Tullberg et al., 2007, Chamen, 2011). This is a very sensible approach, if the wheel effects can be minimised, then "no-till" and CTF and/or LGP have the potential for improved crop production. This is particularly significant in the light of the data from Kroulik et al., (2009) who used global positioning system tracking devices to monitor the field operations for cereal production. Their data revealed that 86%, 65% and 45% of the field was tracked by at least one wheel pass during conventional tillage, minimum tillage and direct drilling/"no-till" respectively. This suggests that much could be gained from combining the benefits of direct drilling/"no-till" with controlled traffic farming practices.

The potential advantages through avoiding compaction from CTF are: -

1. Improved crop yields.
2. Reduced tillage and crop establishment draught forces and energy requirements and
3. Improved soil conditions and infiltration of rainfall and/irrigation water.

Chamen (2011) reported that yield improvements of 7% to 35% have been measured for a range of crops in a number of different international studies. These data are very promising, however, not all of the results were from replicated experiments and soil compaction, if present, was not reported as being alleviated by soil loosening prior to the initiation of the work. These studies did not investigate the effects of LGP.

In order to overcome these issues long term studies have been initiated at Harper Adams University (Smith et al., 2014) where, in an on-going long term experiment, a compacted sandy loam field was chosen to determine the relative effects of: -

1. Random traffic farming (RTF) with 1.2 and 1.5 bar inflation pressure in the front and rear tractor tyres respectively.
2. Lower ground pressure farming (LGP) with 0.7 bar inflation pressure in both the front and rear tractor tyres, and
3. Controlled traffic farming systems (CTF).

These traffic effects are combined with 3 tillage treatments in a 3 x 3 factorial design namely: -

1. Deep tillage (250mm).
2. Shallow tillage (100mm) and
3. No-till.

Following drainage and subsoiling in 2011, the traffic treatments were installed in the autumn of 2012 adopting the traffic intensity (both area and number of passes) of the tillage system as reported in Kroulik et al., (2009). Both deep and shallow tillage operations were conducted using a 4m wide tine/disc/packer combination machine (Vaderstad: Topdown) and the crop sown using a seed drill with disc coulters (Vaderstad: Rapid) for all treatments. Crop establishment in 2012 was difficult due to the wet autumn; however, the grand mean wheat yield at 7.54t/ha was typical for the season (Defra reported a national average of 7.7t/ha).

The overall mean controlled traffic yields in the 4m wide plots were 0.5t/ha (7%) higher than the random traffic yield, with the yield of the low ground pressure system midway between them. Plot widths of 4m were chosen for operational reasons; hence the trafficked area of the CTF plots was 30%. This is a relatively high figure and many CTF farmers are attempting to reduced this to c.15%; e.g., 10 to 12m wide controlled traffic systems with 1.8m - 2m width of traffic lanes. Hence, the mean estimated yields for 15% traffic lane CTF systems are 0.82t/ha (11%) higher than the random traffic yield.

Similarly the estimated first year yield for a 15% traffic lane CTF/"no-till" treatment yielded 0.4t/ha (5%) less than the CTF/deep tillage treatment due to establishment problems of the wheat crop in the traffic lanes in the wet, late autumn conditions. The apparent poor performance of the no-till treatments should be treated with caution at this stage for the following reasons: -

a. The yield is often lower in early years of conversion to zero tillage and will usually increase with time as soil structure and tilth improve and stabilize (Carter, 1994);
b. Calculations that compensate for the low yield in the traffic lanes of the combine harvested data, estimate the yield in the non-trafficked zone to be 8.15t/ha (and the directly measured but very much smaller hand samples yielded 10.51t/ha); and
c. Alternative "no-till" drills may be more suitable for the conditions that prevailed at drilling in 2012 but, unfortunately, were not available at the time.

The effect of the "no-till" traffic lane problem evident in the 2012/13 cropping season was less of a problem during the 2013/14 cropping season with winter barley. The soil conditions in the autumn of 2013 were more favourable and crop establishment with a Vaderstad Spirit drill was approximately one month earlier. So let us not base our judgement on the first year's data alone.

The benefits of "zero traffic" on tillage energy requirements are illustrated by the data given in Chamen et al., (1992 a and b); these show a 60% reduction for shallow ploughing and a 70% reduction for a reduced range of secondary tillage operations over normally trafficked soils.

The results of infiltration studies by Chyba (2012), show a dramatic reduction in infiltration rate with increasing number of wheel passes from 23mm/hour for non-trafficked soils to 4.0mm/hour for 1 tractor pass to 0.5mm/hour for 2 tractor wheel passes. When proportioned in accordance with the area and number of passes of tractor wheels from Kroulik (2008) they give an average infiltration rate of 18.5mm/h for a controlled traffic compared to 5mm/h for random traffic farming. This c. 4-fold increase is in agreement with the field data collected by Chamen (2011).

The on–going study is aimed at showing the longer term affects of combining "no-till" practices with CTF and LGP farming systems and in so doing help to reduce tractor weight/ballast thereby reducing the depths of soil compaction and raise crop yields.

6. Future Research and Development Requirements

Although focused on reduced tillage for cereals in general, rather than "no-till", Davies and Finney (2002) recommended to HGCA that the target areas for research should be: -

1. The collection and development of information and standards in support of machinery selection and management.
2. Optimum agronomic inputs for crops established by shallow tillage.
3. The further development of straw choppers and spreaders, and of cereal drills.
4. Traffic control in cereal production.
5. Reduced tillage to control soil nutrient and pesticide losses in commercial practice as distinct from experiments.
6. The role of tillage in flood control.

Reflecting upon the above there has been little published research for UK soils and residue conditions concerning the development of information and standards in support of machinery selection. Although farmer experience, the machinery trade and consultants share information. However, work has begun at Cranfield University by Professor Rickson to investigate the effects of a selected number of designs of direct drills, which should provide useful data as little research has been conducted in the UK since the work of Earl and Spoor (1994).

Improved straw choppers and spreaders have been commercially developed but these need to be taken a stage further with the advent of 12m wide combine headers, especially when operating in concert with Controlled Traffic Farming (CTF) systems. There is also the need to ensure that discharge augers/conveyors can enable trailers/chaser bins to operate in the adjacent trackways. A number of farmers working in concert with Tim Chamen and the offices of CTF Europe have done much to pioneer CTF systems and currently estimate that approximately 41,000ha in UK is practicing traffic control (with a further 15,000ha in the planning stage).

Fortunately there is good data from both Chamen (2011) and Chyba (2012) concerning the effects of CTF on infiltration and runoff and hence flooding. This, however, needs to be rolled out with catchment scale studies to show the benefits to the nation, in line with the recommendations made by Godwin and Dresser (2003) with respect to soil management in the Parrett Catchment.

As a result of the review, the farm case studies and the advice freely given by many of the specialists the following avenues for future research should be considered: -

Drill design: -

1. Comprehensive investigation into the performance of and improvements to both disc and tine drill types in different soil conditions; especially wet soils with a range of residue lengths and densities. Considering the merits of "hybrid ' systems. Together with the effect

of different levels of soil compaction and the maintenance of seed depth.
2. The determination of the seed density, row widths and location for “combined” seed and fertilizer drilling to optimise crop yield.

Soil and Water Management: -

3. Continuation and extension to a wider range of soil types/agro-climatic regions of the long term Tillage x Traffic study at Harper Adams University. To consider the longer term affects of “no-till” and Controlled Traffic Farming and in particular traffic lane management.
4. Investigate the potential benefits from subsoiling before adopting “no-till”, both with/without Controlled Traffic Farming for a range of soils with particular attention focused on reduced surface disturbance (i.e. Paraplow, Flatlift and similar) techniques to minimise adverse effects of stale seedbed disruption.
5. The development of economical, non-intrusive compaction sensing methods.
6. Promote good drainage for both the effectiveness of drill operation/germination and to assist in the control of blackgrass.
7. Catchment scale studies on the effects of “no-till” and other improved soil management practices on runoff and flood control, and its resilience in the face of climate change, extreme weather events and more intensive agriculture. These could be included in say the Wensum (Norfolk) and Avon (Hampshire) catchments of the Demonstration Test Catchment programme. (http://www.demonstratingcatchmentmanagement.net).
8. The role of ‘no-till’ on short term and long-term soil quality indicators, and its role in sustainable intensification.

Weed, Pest and Nutrient Management: -

9. Investigate the sustainability of “no-till” in the absence of glyphosate.
10. Management of grass weeds (blackgrass and brome) in no-till systems. The use of stale seedbeds and very shallow min-till, inter-row weeding and the place of inversion tillage within the rotation. Investigate the suggestion that blackgrass may become less of a problem with time under “no-till” management, as reported in Chapter 3.7 (3).
11. The control of slugs and snails (a serious problem in limestone soils).
12. Investigate techniques for managing the residual effects of herbicides in “no-till” systems.
13. To determine the effect of “no-till” on spring soil N supplies.

Crop Rotations/Generic Issues: -

14. Investigate the selection and development of alternative economic, non-cereal, spring sown, break-crops.
15. Further development into the use/application of multi-functional autumn-sown mixed cover and companion crops and their benefit in improving maintaining soil structure and control soil moisture levels.
16. To determine (for grassland farmers) the compacting effect of cattle on “no till”/ direct drill sward replacement under the high stocking rate, grazing-based systems.

17. The position of “no-till’ with respect to upcoming policy changes via CAP reform and the development of GAEC guidelines.

7. Conclusions

Both practical farm experience and the literature have indicated that: -

1. “No-till” can offer significant operational and economic benefits: -

    1. Reduction in both fuel and labour.
    2. Establishment cost savings.
    3. Wider drilling window and improved timeliness.
    4. Ease of matching equipment widths.
    5. Improved trafficability.

2. “No-till” can offer improvements to both the soil and the environment: -

    1. Increased soil organic matter, soil organisms and invertebrate activity and as a result; improved soil structure, infiltration and drainage, less soil splash and soil erosion.
    2. Increased topsoil moisture in dry seasons.
    3. More uniform germination across variable soil types.
    4. Lower germination of weeds and a reduction in weed seed burden.
    5. Increased wildlife.
    6. Reduction in Green House Gases.

3. However, to achieve these does come with a number of challenges for improved management: -

    1. Early compaction issues until the soil “stabilises”.
    2. Controlling slugs (after oil seed rape) and snails.
    3. Residue management and “hair pinning” of straw residues when drilling in wet soils.
    4. Grass weeds and the multiplication of weeds not controlled by glyphosate.
    5. Addressing seasonal changes especially in the first five years.
    6. Emergence issues and variation in drilling depth.

4. The above points are included in the requirements for future research and development and in particular help is needed from: -

    1. Engineers and manufactures to further improve equipment: drills, straw choppers and chaff spreaders; and especially improve and adapt dry land machines to wetter conditions.
    2. Agronomists and advisors to adapt appropriate practices and re-train staff and farmers.
    3. Environment Agency, internal drainage boards, contractors and farmers to ensure adequate land drainage.

5. There is evidence that Controlled Traffic Farming may provide a means to help solve the soil

compaction issues enabling less yield reduction in the early years of conversion to “no-till”, especially if the issues in the traffic lanes can be resolved in wet years. The current study should be extended to a wider range of crops and soils with a simplified design.

6. A major risk to the adoption of “no-till” is the management of grass weeds and this is a high research priority. This may have to be via tillage/cultural methods and should be investigated soonest.

7. The training of “best practice” for farm managers, operators, advisors and lecturers is essential so that the benefits can be realised. As also reported by Morris et al., (2014).

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Appendices: Farm Case Studies

Farm Case Study: No 1

Farmer name: Guy Leonard **County:** East Riding of Yorkshire
Cropped area (ha): 440 **Mean Annual Rainfall (mm):** 670
Soil Type(s): Predominately Clay loam
Major Crop Rotations: Winter wheat/spring beans/winter wheat/spring barley/oil seed rape.
Start date for switching to No-Till practices (year): 2012
Did you start through a gradual reduction in intensity of cultivation or through trial no-till areas? Please indicate over what time period this took place?
We experimented with a small area of No-till in the 1990’s, mainly wheat into oil seed rape. Then min-till, full change to no-till in 2012.
What were your reasons for starting no-till farming?
1. Financial
2. Soil health & adding organic matter
3. Environmental

What have been the major benefits?
1. Reduction in fuel and labour
2. An increase in earthworm activity
3. Less soil erosion

What have been the minor benefits?
1. Increased wildlife
2. Increased home life

What major problems have you faced with No-till Farming?
1. Early compaction problems, until soil structure stabilises
2. Slugs, especially after oil seed rape
3. Residue management (even spreading of straw)

What minor problems have you faced with No-till Farming?
1. Hair - pinning when drilling with a direct drill
2. Nitrogen lock up
3. Grass weeds, especially blackgrass

What crop yields do you achieve from No-till v other tillage/seeding practices?
1. Cereals: 11t/ha no-till v 11.5t/ha min till for 1st wheat.
2. Oil seeds: No difference – approximately 4.5t/ha.
3. Spring beans**:** No difference – approximately 6t/ha.

Does this change with seasonal climatic factors?
Yes definitely: not helped with wet soils when combine harvesting.
What equipment do you use?
Weaving - Big Disc Drill for cereals, beans and cover crops.
Claydon Drill for oil seed rape + straw rake, rollers and press.
Primary tractor power available (number of critical tractors and their hp):
2 x 220hp and 1 x 190hp.
How much time is required for crop establishment?
40minutes/ha.
What are the fuel requirements & savings over other tillage practices?
Approximately 1/3 at the current time.
Has no-till allowed you to reduce your total investment in machinery?
Yes massively. A subsoiler is still required to repair any compaction.
Are you still equipped to apply traditional methods to the whole farm - or how much of it?
No. Not equipped to return to min-till.

What are the herbicide requirements in comparison with other tillage practices?
Higher amounts of glyphosate to kill off cover crops.
What are the fertilizer requirements in comparison with other tillage practices?
Too early to judge.
What are the pesticide requirements in comparison with other tillage practices?
Probably 25% more slug pellets.
What are the overall costs of production in comparison to other tillage practices?
25% lower costs, providing yield remains constant.
Under what soil/weather/field conditions is your no-till most superior to traditional methods?
Dry weather and dry soils.
Do you approach no-till on an opportunity basis, depending on season or circumstances, or with the aim of making it a whole-farm technique?
Whole-farm technique.
Do or would you consider combining No-till with controlled traffic farming?
Maybe, but CTF is expensive.

Farm Case Study: No 2.

Farmer name: Edward Bradley and Robert Gent **County:** North Cambridgeshire
Cropped area (ha): Bradley - 50: Gent 320 (Neighbour and drill contractor)
Mean Annual Rainfall (mm): 600 **Soil Type(s):** Skirt, silt, organic fen, heavy clay in places.
Major Crop Rotations: Oil seed rape, Winter wheat, spring beans, spring oats, spring barley.
Start date for switching to No-Till practices (year): 2008
Did you start through a gradual reduction in intensity of cultivation or through trial no-till areas? Please indicate over what time period this took place?
No trial period - direct change.
What were your reasons for starting no-till farming?
1. Time constraints tractor hours and man-hours.
2. Reduce cost of crop establishment.
2. Machinery costs. Reduce tractor hp/ha.
3. Soil status - to increase organic matter % and improve soil structure.
4. The aim is for standalone farming without support payment.
5. Lower the overall cost of crop production, cost per tonne produced.

What have been the major benefits?
1. Time savings.
2. Cost savings.
3. Fuel savings.
4. Increasing organic content due to old root systems remaining and less oxidisation of organic matter.
5. Soil structure and drainage improvement. In the last 2 years of above annual rainfall where neighbouring farms had water standing on the land, even on the heaviest fields with no field drains there was no standing water on no-till fields.
6. In dry and very dry conditions more moisture held in the topsoil.
7. More uniform germination on variable soil types across the field.
8. Wider drilling window. No risk of seedbed ruined by rain events.
9. Ability to drill more acres in the same time. Fewer operations and less man-hours.

What have been the minor benefits?
1. More worm activity - surface drainage.
2. Low soil disturbance leading to less weeds germinating, black grass and broad-leaved weeds.
3. Less puddling on the surface of the soil after heavy rain allowing better infiltration and reduces capping.
4. Less soil splashing onto the crop to spread diseases e.g. eyespot (Prew *et al.*, 1995).

What major problems have you faced with No-till Farming?
1. Dealing with chopped straw residue leading to increase in slug population. Often better results from having straw baled and carted off when fields are dry enough for traffic.
2. In wet weather conditions straw shading soil from drying sufficiently for drilling.
3. Difficult management decision to do nothing pre-drilling apart from watch green cover crops grow. Only spraying weeds/cover crops before drilling.
4. Finding cheap cover crops to get established after the combine, presently using spring oats for over wintered stubble coming into spring beans.

What minor problems have you faced with No-till Farming?
1. Comments from peers and general public - untidy looking fields for a prolonged period of time, particularly if the current crop is spring drilled.
2. People don't realise it has been cropped and walk, ride and drive over the land which has been drilled.
3. After a few years sprayer wheel marks can need rectification.
4. Educating staff not to run on land at harvest only along wheel marks – empty the combine on headlands.

5. Need chaff spreaders on combine.

What crop yields do you achieve from No-till v other tillage/seeding practices?

Cereals - average to better.

Oil seeds - average to better.

Does this change with seasonal climatic factors?

Changes are similar to those of conventionally drilled crops and are probably better with no soil structure damage. Attention to more vigorous varieties. Placement fertiliser helps.

What equipment do you use?

750A John Deere, low surface disturbance subsoiler, straw harrows, rolls and slug pelleters. Self propelled sprayer 36m.

Primary tractor power available (number of critical tractors and their hp):

1 x 300hp Rubber tracked crawler, 1 x 160hp 4WD drilling and other

How much time is required for crop establishment?

Subsoiler 4 ha/h. Drilling 4 ha/h.

What are the fuel requirements & savings over other tillage practices?

Only uses ⅓ of fuel you would normally use.

Has no-till allowed you to reduce your total investment in machinery?

Yes.

Are you still equipped to apply traditional methods to the whole farm - or how much of it?

25% of the farm could be farmed using traditional method in the comparable amount of time. No comment.

What are the herbicide requirements in comparison with other tillage practices?

Higher glyphosate usage, otherwise the same as traditional methods.

What are the fertilizer requirements in comparison with other tillage practices?

The same at present.

What are the pesticide requirements in comparison with other tillage practices?

The same.

What are the overall costs of production in comparison to other tillage practices?

Cultivation and establishment costs are reduced by 50%. Combining the same.

Under what soil/weather/field conditions is your no-till most superior to traditional methods?

Dry conditions.

Do you approach no-till on an opportunity basis, depending on season or circumstances, or with the aim of making it a whole-farm technique?

Whole-farm technique. However, in some adverse weather conditions such as autumn 2012 and 2013 cropping changed to some spring drilling and cultivations required in establishing the crop.

Do or would you consider combining No-till with controlled traffic farming?

No-till system leaves the root systems from previous crops, which carries the machinery without soil damage - so it isn't necessary. Also, cannot justify the costs of new or modified machinery required for CTF.

Please provide any other comments and information that you consider pertinent.

1. Need to move towards companion cropping for pest management and for the benefit of the crop.
2. To help with trash problems take straw off the field with a self-loading forage wagon (Pottinger or Reco Strutmann), to save a pass with tractor and bale catcher, taking straw to a static baler sited elsewhere.
3. To lower the carbon footprint of modern farming no-till must be the way forward.
4. Countering the threat from Government for taxes on the environmental impact of intensive farming.
5. Over wintered stubbles and cover crops can only benefit wildlife while improving the soil.
6. Soil Protection Review appears to have been written with min or no-till in mind.

Farm Case Study: No 3

Farmer name: Tony Reynolds **County:** Lincolnshire/Leicestershire
Cropped area (ha): 1250 **Mean Annual Rainfall (mm):** 750 mm
Soil Type(s): Peat Fen to 90% clay and everything in between
Major Crop Rotations: 40% first wheat, 20% second wheat, 20% OSR, 20% spring barley
Start date for switching to No-Till practices (year): 2002

Did you start through a gradual reduction in intensity of cultivation or through trial no-till areas? Please indicate over what time period this took place?
Over 2 years on one farm, the rest instantaneous 2004.

What were your reasons for starting no-till farming?
1. Low soil, organic, carbon
2. Erosion – both wind and water
3. Need to improve soil fertility

What have been the major benefits?
1. Huge increase in soil organisms and invertebrate
2. Reduction in erosion, more friable soil
3. Reduction in weed seed burden

What have been the minor benefits?
1. Fuel saving
2. Labour saving
3. Massive increase in wildlife

What major problems have you faced with No-till Farming?
1. Every year presents new problems and has since we started.
2. Multiplication of weeds not controlled by glyphosate.
3. The soil itself changes dramatically during the first five years, after which it stabilizes. The higher the clay content the longer it takes.

What minor problems have you faced with No-till Farming?
1. Making machinery that is designed for dry conditions operate in the wet.
2. Understanding the differing roles in the seed dressing, spraying residuals and pre-emergence when the soil has not been moved.
3. Teaching our Agronomists to relearn their trade.

What crop yields do you achieve from No-till v other tillage/seeding practices?
Crop yields in general reduce over the first 2/3 years, more so on heavy clay soils, years 4/6 they return to normal levels, here on the home farm, our yields are now generally higher than they were before we started, which is fantastic.

Does this change with seasonal climatic factors?
Yes, some years are better than others, some worse.

What equipment do you use?
Drills – we have a 4m and 6m Great Plains and a 4m and 6m Edward Weaving Drill. All are disc type coulters.

Primary tractor power available (number of critical tractors and their hp)
The power required to drill runs at approximately 20-25 horse power per metre.

How much time is required for crop establishment?
We just drill, we do not roll or stubble rake.

What are the fuel requirements & savings over other tillage practices?
Our average fuel consumption with classic agriculture ran at 92-96 litres per hectare for all operations. Our last 3 year average is 42.5 litres per hectare for all operations.

Has no-till allowed you to reduce your total investment in machinery?
Yes.

Are you still equipped to apply traditional methods to the whole farm - or how much of it?
No.

What are the herbicide requirements in comparison with other tillage practices?
Pretty much the same, we may use more stubble cleaning sprays.
What are the fertilizer requirements in comparison with other tillage practices?
Big reduction in P&K requirements, whilst this changes year on year, we have reduced by between 40 and 60%.
What are the pesticide requirements in comparison with other tillage practices?
Broadly the same, but we are now noting material reduction in black grass as a problem weed.
What are the overall costs of production in comparison to other tillage practices?
Approximate reduction of £160-£200/hectare.
Under what soil/weather/field conditions is your no-till most superior to traditional methods?
Much better in the dry. We are learning how to cope the last two years of wet soil.
Do you approach no-till on an opportunity basis, depending on season or circumstances, or with the aim of making it a whole-farm technique?
No-till or CA is not a husbandry regime that one can go in and out of. It is the accumulation over years of soil chemistry undisturbed that makes the system work.
Do or would you consider combining No-till with controlled traffic farming?
We keep looking.

Farm Case Study: No 4

Farmer name: Nick August **County:** Oxfordshire
Cropped area (ha): 404 **Mean Annual Rainfall (mm):** 850
Soil Type(s): Silty Clay loam, Cotswold brash, Kimmeridge clay and lower green sand.
Major Crop Rotations: Winter Wheat, Winter OSR , Winter Wheat, Peas
Start date for switching to No-Till practices (year): 2008
Did you start through a gradual reduction in intensity of cultivation or through trial no-till areas? Please indicate over what time period this took place?
2007. Reduced cultivation to 1 primary pass, then drill, while testing the capabilities of direct drilling.
What were your reasons for starting no-till farming?
1. Cost saving
2. Controlled Traffic Farming
3. Improved function of direct drill over min-till

What have been the major benefits?
1. Cost saving
2. Timeliness
3. Soil structure

What have been the minor benefits?
1. Easier to match equipment widths with consideration to CTF
2. Speed of soil recovery from major weather events
3. Trafficability of soil

What major problems have you faced with No-till Farming?
1. Complacency of drill manufacturers to improve product
2. % seed emergence (56% with "no-till", 70% with minimum tillage)
3. Snails

What minor problems have you faced with No-till Farming?
1. Variation of drilling depth across width; shallow in wheelings, deeper in non-trafficked soil.
2. Trash management
3. Transition to CTF; poor straw chopper and chaff spreader performance on combine.

What crop yields do you achieve from No-till v other tillage/seeding practices?
1. Cereals slightly less.
2. Oil seeds same.
3. Other peas: improved.

Does this change with seasonal climatic factors?
I have no comparison yields, but trials of direct, strip, and min-till, establishment of wheat crop this season.
What equipment do you use?
Vaderstad Seedhawk, 8m.
Primary tractor power available (number of critical tractors and their hp):
1 x 200hp, 1 x 150hp.
How much time is required for crop establishment?
26.33 min/ha including rolling, (Strip till 28.63 min/ha, min-till 54.2 min/ha) work rate in field not including travel, and filling/down time.
What are the fuel requirements & savings over other tillage practices?
Direct drill 4.70 l/ha, strip till 10.72 l/ha min-till 17.83 l/ha for all crop establishment tillage.
Has no-till allowed you to reduce your total investment in machinery?
Yes, £5000/yr.
Are you still equipped to apply traditional methods to the whole farm - or how much of it?
Yes, all. Equipment kept for contract work.
What are the herbicide requirements in comparison with other tillage practices?
Reduced, but with more use of glyphosate

What are the fertilizer requirements in comparison with other tillage practices?
Initially increased. No mineralised nitrogen leaves the crop “hungry” going into the winter.
What are the pesticide requirements in comparison with other tillage practices?
Much the same. Snails are now more of a problem than slugs, and harder to kill. I may consider rolling as opposed to straw harrowing as a pre-drilling control method.
What are the overall costs of production in comparison to other tillage practices?
About £6.70/tonne cheaper compared to min-till.
Under what soil/weather/field conditions is your no-till most superior to traditional methods?
In nearly all weather conditions no-till is better, clay soils have to be in Controlled Traffic Farming (CTF), and operations timely. Sandy soils also benefit from CTF, with the added advantage that no-till reduces metal wear rates. All operations benefit from higher organic matter, and this has greatest beneficial impact on seedbed preparation when near the surface, as in no-till.
The exception is on spring cropped heavy soil, when the weather does not allow the soil surface to dry. In this instance cultivation operation pre-drilling may be required.
Do you approach no-till on an opportunity basis, depending on season or circumstances, or with the aim of making it a whole-farm technique?
It’s a whole farm technique, where any tillage is an extreme exception.
Do or would you consider combining No-till with controlled traffic farming?
Yes, I have done for 5 years.
Please provide any other comments and information that you consider pertinent.
Rotational spring cropping has eased the burden of blackgrass control, and cover crops help with soil conditioning, fertility, and organic matter. Lack of mineralised nitrogen to help autumn vigour in winter crops can be a problem, being more profound in cold dreary seasons; however, crops seem to catch up in the spring.

Farm Case Study: No 5

Farmer name: S. Salbstein Ltd (Chris and Tom Reynolds**)** **County:** Kent
Cropped area (ha): 800 **Mean Annual Rainfall (mm):** 800mm variable over the last 10 years.
Soil Type(s): From heavy gault clay through to grade 2 brick earth and chalk soils
Major Crop Rotations: Wheat, Rape, Wheat, Other spring break (beans, linseed, peas or oats). We also grow quite a large area of hybrid winter barley for seed, in place of wheat on certain blocks .
Start date for switching to No-Till practices (year): Spring 2013
Did you start through a gradual reduction in intensity of cultivation or through trial no-till areas? Please indicate over what time period this took place?
We went straight in from a previous min-till system. We still use that when we have to incorporate sewage sludge.
What were your reasons for starting no-till farming?
My nephew, Tom, had spent a year zero till drilling in New Zealand and was impressed with the results. My brother has been zero tilling for about 4 years in the Weald of Kent, also successfully.
What have been the major benefits?
1.Very impressed with the state of the ground during this last winter which was unprecedentedly wet…. namely 787mm rain Oct-Feb inclusive.
2.Saving in establishment cost.
3.Because of less work to be done to the land, it improves the timeliness of crop establishment.
What have been the minor benefits?
This has facilitated the introduction of cover crops and the ability to drill straight into them afterwards.
What Major problems have you faced with No-till Farming? None
What minor problems have you faced with No-till Farming? None
What crop yields do you achieve from No-till v other tillage/seeding practices?

4. Cereals. No comparisons as yet, large areas of winter crops this year look well.
5. Spring rape 2013 3t/ha.
6. Spring Beans 2013 4.2t/ha.
7. Linseed 2013 the zero till drilled exceeded the conventional rapid drilled by 25% undoubtedly due to going into moisture and growing straight away, whereas conventional seeding tended to dry out a bit.

Does this change with seasonal climatic factors? Insufficient seasons
What equipment do you use? 6m Vaderstad Seed Hawk
Primary tractor power available (number of critical tractors and their hp):
1 x 270hp, 1 x 210hp, 1 x 230hp
How much time is required for crop establishment?
Drill output is on average about 30-40ha per day depending on conditions and the serviceability of the drill.
What are the fuel requirements & savings over other tillage practices?
Not fully quantified as yet.
Has no-till allowed you to reduce your total investment in machinery?
It has meant that we have not upgraded some of our other cultivation kit.
Are you still equipped to apply traditional methods to the whole farm - or how much of it? Yes, to cover contracting needs.
What are the herbicide requirements in comparison with other tillage practices?
Very similar.
What are the fertilizer requirements in comparison with other tillage practices?
We feel that some crops would benefit from some N at drilling to make up for the lack of N released by nitrification from tillage. Particularly winter rape and winter barley depending a little on drilling date.

What are the pesticide requirements in comparison with other tillage practices?
No difference at this moment, hopefully this might reduce over time.
What are the overall costs of production in comparison to other tillage practices?
Approximately £45-50 /ha less. We have not seen a reduction in other kit because as contractors we have to be able to offer all types of establishment.
Under what soil/weather/field conditions is your no-till most superior to traditional methods?
The drier the better. Probably 2 weeks earlier in the autumn and 2 weeks in the spring.
Do you approach no-till on an opportunity basis, depending on season or circumstances, or with the aim of making it a whole-farm technique?
We will try to maximise the area of no-till with the continued exception of sewage sludge incorporation.
Do or would you consider combining No-till with controlled traffic farming?
Yes, we are heading towards drilling on an angle to the tramlines and then reinstating the 30m tramlines with the sprayer using RTK. The only other wheeling tracks are those of the combine at 10.5m on tracks and 2x straw rake at 7.5m on different angles and large section tyres. We try to keep grain trailers to tramlines or edge of field depending how dry it is at harvest.
Please provide any other comments and information that you consider pertinent.
We have had fairly major reliability and efficacy problems with the drill. The Seed Hawk coulters are excellent, but the hydraulic system is complicated and the operation of the control box is less intuitive than the earlier Swedish design.