BBRO 14/04: A review of strip tillage for sugar beet production – A desk study

NL Morris (Farming Systems and Soils Specialist)

NIAB
Huntingdon Road
Cambridge
CB3 0LE

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Summary

Strip tillage is increasingly being used for wide row crops such as sugar beet, maize and oilseed rape in a number of geographical regions of the world including North America, New Zealand and Europe. Strip tillage has been shown to reduce costs of establishment through increased speed of working and an improvement in the timeliness of such operations. Less soil disturbance generally reduces the emergence of broad leaved weeds. The aim of strip tillage is to produce a narrow, residue-free, cultivated zone that is suitable for drilling crops into whilst leaving a significant area uncultivated. Specific configuration of the implement depends upon factors such as soil type, soil moisture conditions and the timing of cultivations.

Cultivation timing is critical to the success of strip tillage and is considered to be the most important factor for any practitioner planning to use strip tillage to create the desired seedbed conditions for sugar beet. To ensure that strip tillage is successfully employed a number of considerations are required including the use of GPS (RTK) guidance, the timeliness of operations and the depth of soil disturbance. These all have an impact on the quality and uniformity of the strips created. The timing of strip tillage operations depend upon soil type; on light soil types a single strip tillage operation is sufficient, however, on medium and heavy soil types (18-45% clay content) it is best to complete strip tillage cultivations at two timings; once in the autumn when the soil is relatively dry and again in the spring to 'freshen up' the strip prior to drilling. In either circumstance drilling is best completed as a separate operation to ensure consistent and uniform seed placement.

The integration of strip tillage with alternative management techniques e.g. inter-row weeding, fertiliser placement or controlled traffic farming could bring further cost reductions in growing sugar beet. However, further research to quantify these techniques in the UK would seem prudent.

1. Introduction

The objective of this report is to review how strip tillage is currently being used in sugar beet in the United Kingdom (UK) and across Europe. This desk study will serve to identify key areas for future research and develop further the guidelines for the use of strip tillage for sugar beet production in the UK.

Strip tillage is increasingly being used for wide row crops such as sugar beet, maize and oilseed rape in a number of geographical regions of the world including North America, New Zealand and Europe. Strip tillage has been shown to offer many benefits both economically (reduced fuel inputs and decreased labour costs due to fewer field operations; Overstreet, 2009) and environmentally (by reducing soil and wind erosion through crop residue retention). Data suggests that this can more than halve the fuel usage associated with crop establishment (*cf.* plough based systems), lower broad leaf weed burdens (through reduced soil disturbance between rows) and also reduce labour costs and the number of field operations. In addition studies in the United States, Canada and the UK (Morris *et al.*, 2010b) have demonstrated strip tillage improves work rates with fewer field operations and, in some circumstances, can offer improved margins compared to inversion tillage.

This review will improve the current understanding for the potential to use strip tillage in sugar beet production in the UK. Outputs from this project will enable growers to make more informed decisions by using a decision support tool by means of a flow diagram detailing under which conditions strip tillage is most likely to be effective. The information gathered as part of the literature review will identify any outstanding research and knowledge transfer requirements that would enable growers to utilise strip tillage techniques more effectively in the UK for sugar beet production.

2. Defining tillage approaches

Current tillage systems within the UK can be divided into two broad categories;

- inversion tillage, known as conventional tillage, whereby a sequence of operations are used to prepare a seedbed including complete soil inversion to bury or incorporate crop residue and is usually accompanied by additional cultivation to create a seedbed (Carter *et al.*, 2003).
- Conservation tillage, known more widely within the UK as non-inversion tillage, includes systems that involve fewer passes than conventional tillage, but incorporate crop residue into the surface (upper 20cm) whilst still leaving at least 30% of crop residue on the soil surface (Davies and Finney, 2002).

One further method of non-inversion tillage, known as direct drilling leaves the soil completely undisturbed from harvest until crop sowing, all crop residues remain on the surface; seed placement is achieved by discs, coulters or chisels opening a narrow slot where the seed is delivered.

The particular tillage system chosen will depend on what particular crops, soil types and production systems are being used by the grower and the potential of a particular system for reducing costs whilst optimising production and financial margins. A summary and classification of the tillage systems according to tillage intensity can be seen in Figure 1.

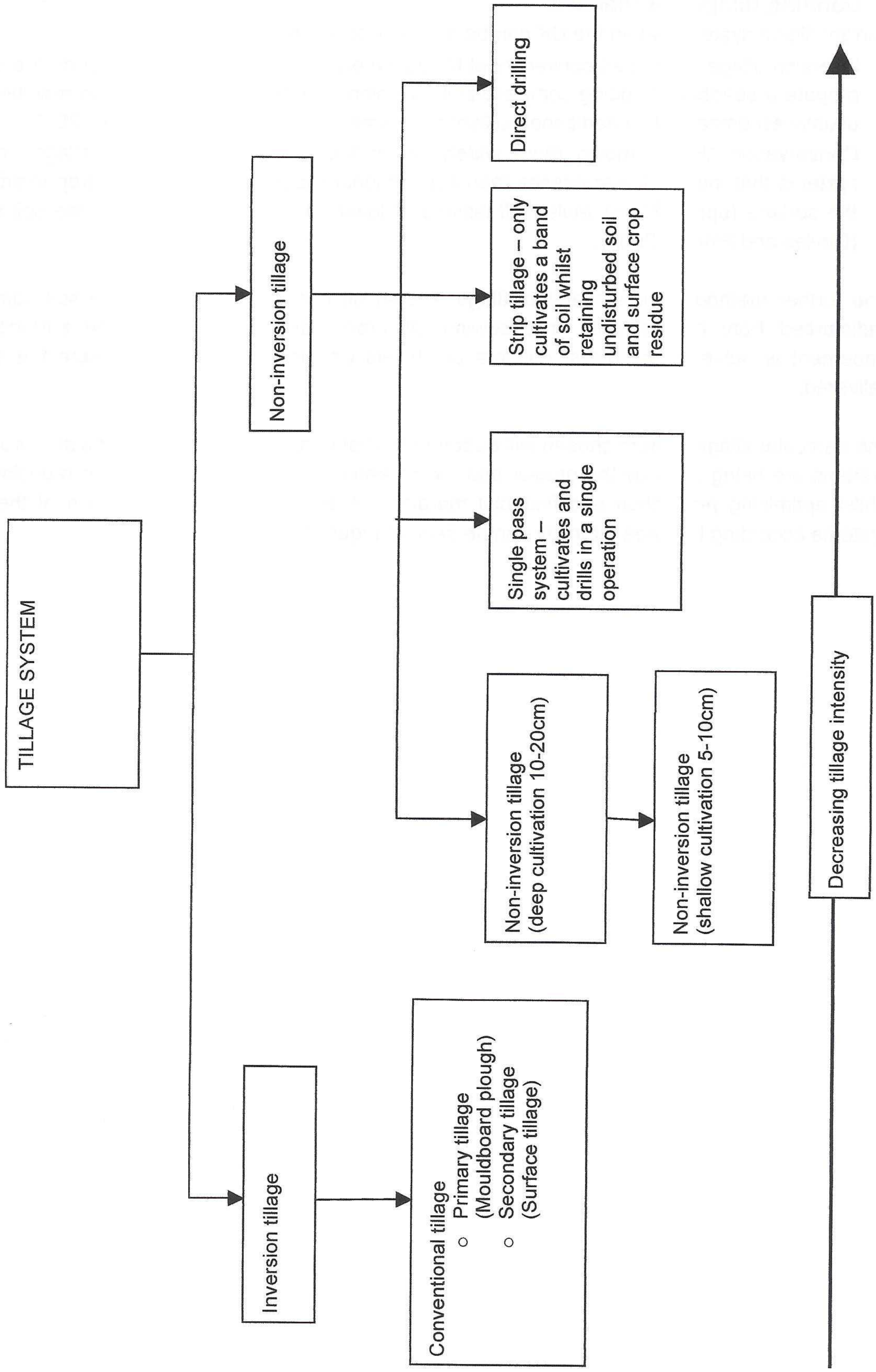

Figure 1: Classification of tillage systems in relation to tillage intensity (Morris *et al.*, 2010a).

2.1 Glossary of tillage terms

Definitions adapted from Morris *et al.* (2010a).

Inversion tillage – Also known as conventional tillage. Primary tillage is the initial major operation and involves inverting the soil using a mouldboard plough. Secondary cultivation includes the use of a single or double pass of a cultivator to produce a suitable seedbed for drilling.

Non-inversion tillage – Non-inversion tillage refers to a cultivation system that usually involves fewer passes than conventional tillage with implements working at shallow depths (5–10cm) whereby much of the crop residue remains on the soil surface or to deeper depths (15–20cm) whereby crop residues are mixed into the topsoil but leave a proportion on the soil surface.

Conservation tillage – Conservation tillage describes any tillage system that maintains at least 30% residue cover on the soil surface after drilling to reduce water or wind erosion. Typically single-pass systems, strip tillage and direct drilling could all be considered as conservation tillage approaches.

Single-pass systems – Single pass systems describes a tillage system that cultivates the soil and drills the crop in a single operation. Typically soil disturbance is greater than that of strip tillage or direct drilling but less than that of non-inversion tillage. Typically single-pass systems disturb 70-100% of the soil surface.

Strip tillage – Strip tillage is a modification to a direct drilling system where disturbance of less than one third of the total field is cultivated. Cultivation and drilling operations can either be completed at a single timing or at separate timings depending on soil and crop type. Tillage occurs in strips or bands, loosening the soil only along the line of the seed drill leaving between row areas undisturbed and covered in crop residues.

Direct drilling – Direct drilling refers to the sowing of crops directly into the previous crop stubble with no prior cultivation since harvesting the previous crop and with all crop residue left on the soil surface. Direct drilling implements consist of a series of tines or discs that cultivates a shallow, narrow band of soil that creates an environment suitable for the seed which is then placed behind the coulter and firmed by a rear roller or harrow.

2.2 Description of strip tillage

Strip tillage is a modification to direct drilling where cultivation occurs directly into crop stubble. The aim of strip tillage is to produce a narrow, residue-free, cultivated zone that is suitable for drilling crops into whilst leaving a significant area uncultivated (Morris *et al.*, 2007). The zone of cultivated soil is typically 20-25cm wide and 7-10cm high when created, this settles to 1-2cm high in spring prior to drilling (Figure 2). Residue in the tilled strip has usually been moved to the untilled strip and drilling then takes place with the seed being drilled into the centre of the loosened strip (Morris, 2009). Forward speed of strip tillage operations is typically between 8-12km/h to ensure sufficient soil disturbance by the tine.

Figure 2: Strip tillage cultivation creating a defined cultivated zone.

2.3 What do we aim to achieve by using strip tillage?

By using strip tillage in sugar beet the aim is to optimise soil structure of the seedbed and consolidate the soil profile to produce a uniform seedbed. Sugar beet requires the preparation of a seedbed to a depth of 5-7cm aiming for a minimum of 30% particles less than 3mm around the seed to improve availability of moisture to seed (Anon, 2014).

By using strip tillage there is potential to:

- Reduce wind velocity at the soil surface by up to 50% (Overstreet, 2009) and consequently greatly reduce the risk of wind erosion.
- Reduce soil erosion and outflow by around 88-95% compared to plough tillage (Billen *et al.*, 2013).
- Reduce crop establishment costs through increased work rates (*cf.* Inversion tillage) and lower fuel consumption (Morris *et al.*, 2010b).
- Reduce the emergence of many broad-leaved weed species through reduced soil disturbance (Froud-Williams *et al.*, 1983).
- Maintain soil organic matter that plays a key role in the fertility, function and structure of our soils.
- Integrate strip tillage with alternative management practices such as inter-row weed control, cover cropping or controlled traffic farming to improve resilience within our farming systems.

2.4 Where is strip tillage currently being used commercially in the UK?

Currently the use of strip tillage for sugar beet establishment in the UK has not been widely adopted. However, with growers looking to manage establishment costs the potential to reduce fuel costs and increase work rates can be attractive. On soil types that are prone to erosion the technique also negates the requirement to grow a barley cover crop prior to establishing the sugar beet. Whilst strip tillage is not new it has been relatively slow to be adopted within Europe, although with machinery manufactures now developing implements better suited to UK soil types and conditions there is becoming an increased interest to explore the potential for strip tillage in sugar beet.

As briefly discussed by Ecclestone (2014) some growers have been considering how they could utilise strip tillage on some heavier silty clay soils where ploughing is expensive and can lead to slumping over the winter period. In these situations growers have either established a number of fields using the technique or split fields to compare strip tillage to conventional tillage. Initial results have been positive with regard to crop emergence and it has also been noted that weed beet levels were lower than expected. Some growers will continue to trial the technique in 2014 and with a number of strip tillage machines adapted to European conditions and with increasing interest in the technique further information to inform growers on the suitability of the technique should become available.

More widely strip tillage in the UK has been shown to be an effective establishment method in wide row crops including oilseed rape where studies carried out at NIAB TAG delivered through the National Agronomy Centre (NAC) initiative in 2009, 2010 and 2011 showed comparable yield results to plough tillage and opportunities to maintain or increase margin over establishment costs. With the increased land area cultivated to maize for use in anaerobic digestion (AD) plants, strip tillage has shown the potential for reducing establishment costs. The placement of the digestate into the strip prior to drilling the maize is potentially allowing growers to improve early crop establishment through fertiliser placement and improved fertiliser use efficiency.

3. Implementation of strip tillage

3.1 Implement configuration

Implement configuration is predominantly devised around a toolbar with individual units mounted directly onto the toolbar to ensure each unit can follow ground contours independently. The main components for a strip tillage implement are shown in Figure 3 and further described below. Components can be added to allow the implement to work in a range of soil types and farming systems.

Components include:

1) Tool frame – Each unit is mounted to the tool frame at a set row spacing, typically 50cm for sugar beet.
2) Parallel linkage – The parallel linkage ensures that each unit follows ground contours independently and the parallel linage can either be sprung or use gas accumulators to ensure a constant down pressure is applied to maintain a consistent working depth at all times.
3) Tined row cleaner – The tined row cleaner is used to move crop residue present within row to between row and ensures the tilled strip remains free of crop residues.
4) Disc coulter – The disc coulter opens the strip and cuts through any remaining crop residue. To ensure sufficient soil disturbance different discs can be used including smooth, notched or wavy discs.
5) Tines – Many different tines can be used to loosen the soil within the strip and typically disturbs the soil to a depth of between 5cm and 30cm. Tines which can apply either liquid or dry fertiliser can also be added to place fertiliser near to the seed.
6) Closing discs and other packers – To ensure that the soil is retained within the cultivated strip a pair of discs are set to retain soil and create a fine, level seedbed. Additional packers can be added behind the closing discs to ensure further seedbed consolidation is achieved. These can typically be iron finger wheels, rubber tyres or rolling baskets.

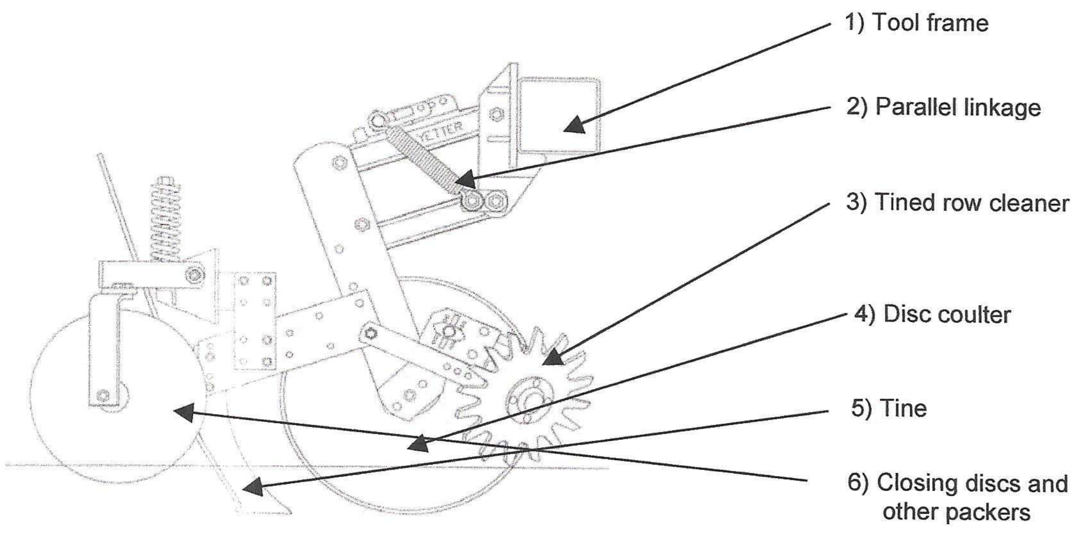

Figure 3: Implement configuration of a strip tillage implement.

Specific configuration of the implement depends upon factors such as soil type, soil moisture conditions and the timing of cultivations. Each of these factors is discussed in further detail in the following sections.

3.2 RTK guidance

It is essential that whatever strip tillage implement is used an RTK global positioning system (GPS) +/- 2cm repeatable accuracy is fitted to the machinery to ensure accurate operation of strip tillage, particularly where strip tillage cultivation is performed in the autumn, followed by drilling in spring. This will allow pass-to-pass accuracy across the field to ensure the cultivated strips are equally spaced and field operations (e.g. drilling) are repeatable to ensure that the seed can be placed within the centre of the cultivated strip without the risk of "drift" (Knight *et al.*, 2009).

Ongoing development with RTK technology is looking to fit units to both the tractor and implement to ensure that on undulating ground the position of the cultivated strips is maintained without the risk of the weight of the implement "dragging" the implement downhill. To achieve this an additional GPS receiver with control unit is fitted to the implement (Figure 4) and adjustments are made to the position of the implement using hydraulic adjustment.

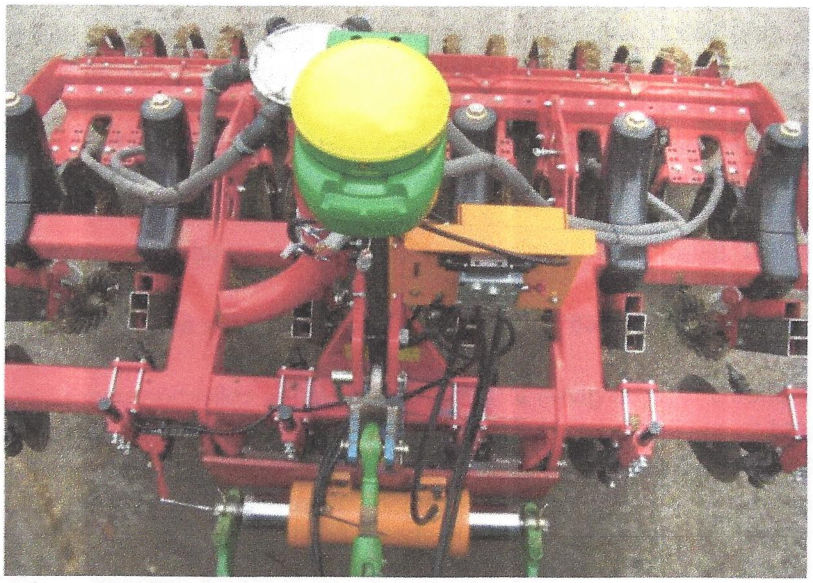

Figure 4: RTK implement shifting using hydraulic adjustment.

3.3 Cultivation timing on a range of soil types

Cultivation timing is critical to the success of strip tillage and is considered to be the most important factor for any practitioner planning to use strip tillage to create the desired seedbed conditions for sugar beet (Pers com. Hermann, 2014; Leforestier, 2013 and Nielsen, 2014). Critically strip tillage cultivation is dependent on soil type (see Figure 5) where typically cultivation can be divided into two approaches (Pers comm. Nielsen, 2014):

1. One pass establishment systems – suited to sandy soils or silt soils
2. Multiple pass systems – particularly for heavy clay soils

Irrespective of soil type strip tillage cultivation(s) should completed as a separate operation to that of drilling. This is to ensure that the working speed for strip tillage operations can be maintained at forward speeds of between 8-12km/h without the risk of affecting seed placement during the drilling operation.

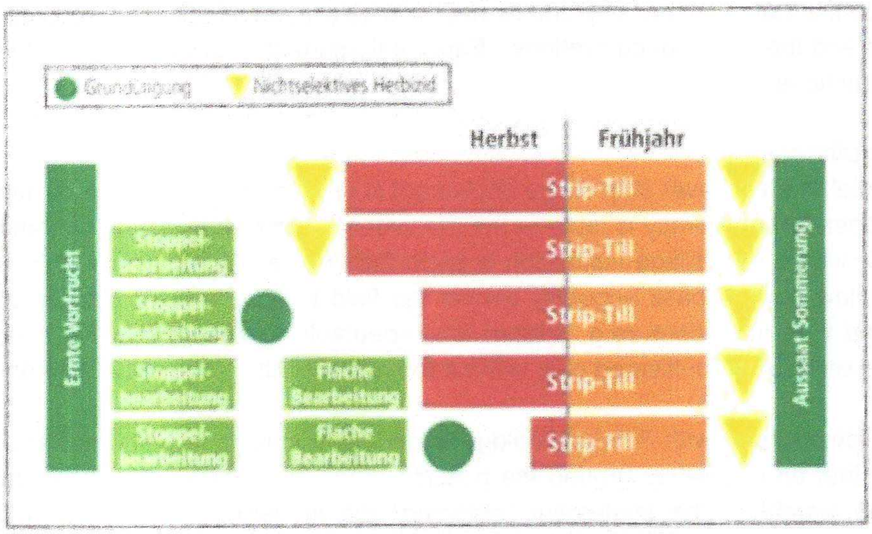

Figure 5: Cultivation timing for strip tillage in southern Germany divided between autumn or spring timing according to soil type (Hermann *et al.*, 2012).

Within the UK strip tillage suitability will be primarily driven by soil type and specifically the clay content of the soil. The following soil categories (after Mullins, 1991) have been listed to assist in defining soil types that are suited to strip tillage within this report.

- Light soil types - <18% clay content – Ideally suited to strip tillage.
- Medium soil types 18-35% clay content – Suitable for strip tillage given correct cultivation timing.
- Heavy soil types 35-45% clay content – Some suitable for strip tillage given correct cultivation timing.
- Very heavy soil types >45% clay content – Unlikely to be suited to strip tillage.

Consideration should also be given to harvesting or straw collection operations from the previous crop with regard to soil structure damage. In these situations where soil structure may have been compacted to below the depth of typical soil cultivations e.g. 20cm then alleviation through inversion tillage systems would be deemed more appropriate and therefore this is unlikely to be suited to using strip tillage to establish sugar beet (see 3.4 – Quality and uniformity of seedbed for further information). Fields that also suffer from a high pressure of grass weeds that are difficult to control in sugar beet are also unlikely to be suited to using strip tillage to establish sugar beet.

3.3.1 Light soil types

Cultivation timings on light soil types are less critical than on heavy soils and can be completed within 2-4 weeks ahead of drilling operations in the spring. One distinct advantage of less soil disturbance is the reduction in soil moisture loss during tillage operations. On light land prone to drought this can be advantageous to ensure the sugar beet germinates rapidly. Results from Morris *et al.*, (2010b) indicated that cultivation on the light land soil type could be completed during the spring either in early spring (early or mid February) or late spring (mid March to early April) with no significant impact to yield or quality compared to plough tillage.

Where soil erosion is a concern then leaving the soil either as stubble or by establishing a cover crop (see 3.8.2 – The use of cover crops in strip tillage) would seem prudent to negate the risk of soil erosion. By using strip tillage the area left undisturbed with stubble can be an effective method in reducing soil erosion by wind by reducing wind velocity at the soil surface by up to 50% (Overstreet, 2009).

3.3.2 Medium and heavy soil types

Cultivation timing using strip tillage, as with any cultivation approach, on medium and heavy soils are much more time critical to achieve the desired seedbed in the spring compared to light soil types. Therefore, the primary strip tillage cultivation is often completed in early autumn, prior to significant rainfall and when the soil is relatively dry. There are three approaches taken for autumn strip tillage cultivation including:

- Strip tillage directly into stubble
- Pre-cultivation *fb* strip tillage
- Pre cultivation *fb* establishment of cover crop *fb* strip tillage.

On heavy land tillage operations are required to be carried out in late summer / early autumn whilst the soil is relatively dry. A light surface cultivation can be completed, that can serve two purposes, firstly, it levels and spreads crop residue evenly across the field (Hermann, 2013). Secondly, it can act as a stale seedbed to encourage volunteers or weed seeds to chit.

Research in Germany indicated that the primary strip tillage operation should be completed using tines set to cultivate to between 15cm and 25cm to improve drainage through the soil profile and to create sufficient 'soil heave' to create a mound of soil for weathering over the winter period (Hermann, 2012). This depth of operation can be less successful on soils with lower organic matter levels and often the strips created 'slump' over the winter period and are difficult to rectify in spring for appropriate seedbeds. In these situations the tines should be set to work the soil at a depth of 12-15cm (Hermann, 2012).

In some situations, if appropriate, cover crops can be established post-harvest and provide soil cover during the autumn / winter period (see 3.8.2 – The use cover crops in strip tillage for further information).

Further to the primary cultivation in autumn a shallow cultivation in the spring is required to 'freshen up' the bands; this is often completed to a depth of 5-7cm with the use of GPS-RTK to ensure that the cultivation is aligned to the band cultivated in the previous autumn (see Section 3.2 – RTK Guidance). To freshen up the strip in the spring Nielsen and Hermann (Pers comm., 2014) suggested that it is necessary to use discs (either smooth or wavy) rather than tines so that the soil is retained in the cultivated strips.

Some studies in Germany, where a period of frosts allowed strip tillage operations to work on land during December, resulted in reasonable strips being created ahead of the spring. However, these operations were a high risk procedure and if the ground was not frosted to sufficient depth then 'slots' were created where the soil was too wet (Pers comm. Hermann, 2014). It should be considered that in the UK where a period of sufficient 'hard frosts' over the winter period are less likely than in other European regions then this strategy would seem unwise and could likely lead to poor seedbed conditions in the spring.

Some operators in Germany on very heavy clay soil (clay content >40%) have moved away from using low disturbance tines and have used deep loosening tines to create a rough seedbed that is open to weathering over winter and is ready to drill directly into in spring (see Figures 6 and 7). One factor that allows this operation to be successful on very heavy clay soils is the reliance on cold winters and frosts below -15°C for a period of time (Pers comm., Horsch, 2014). This approach, therefore, maybe less suitable for UK conditions where the soil may not experience sufficient cold periods to breakdown the ridges to create a suitable tilth.

Figure 6: Ridge tillage in autumn to produce a rough seedbed prior to weathering (Image courtesy of Michael Horsch).

Figure 7: Planting on ridges in spring after weathering (Image courtesy of Michael Horsch).

3.4 Quality and uniformity of seedbed

To ensure that strip tillage produces a uniform seedbed it is necessary to consider field operations in the previous crop, these include:

- Field traffic (including harvesting operations)
- Straw distribution

Field traffic, particularly from previous harvesting operations can be a particular problem to produce a suitable seedbed from either single or multiple strip tillage operations. Either grain trailers or the baling operation and the carting of straw bales off the field can lead to extensive random traffic passes across the field. Often these operations are hauling substantial loads of approximately 20t+ when fully laden. These loads can cause soil compaction that can be problematic for strip tillage cultivation. In these scenarios the uniformity of the cultivated strips (Figure 8) can be variable resulting in reduced crop performance. It is therefore necessary to consider fitting grain trailers with low ground pressure tyres so that any damage can be rectified using a light, shallow cultivation. Baling operations can be difficult to limit traffic movements and therefore consideration for which fields that are suitable to use strip tillage must be given; possibly chopping rather than baling straw in these situations is preferred or by using Controlled Traffic Farming (CTF) that limits traffic to specific traffic lanes in the field.

Figure 8: Variable seedbed uniformity due to harvest wheelings causing soil compaction.

Poor seedbed uniformity can also occur if chopped straw is not distributed evenly across the full width of the combine header width. Again, mats of straw can impair implement performance resulting in 'slots' (Figure 9) being created. These 'slots' are either created due to the mats of straw retaining moisture within the soil profile or as a result of an incorrect working depth resulting from the implement riding out of the ground (Pflugfelder, 2013). Morris *et al.* (2010b) also reported that during field experiments mats if wet straw also tended to reduce the flow of material through the implement resulting in implement blockages.

To ensure that crop residue is evenly distributed across the full working width of the header the combine should be appropriately set. If straw residue is not uniformly spread then consideration should be given to using a straw rake to distribute the straw evenly across the field. Often this can be completed at an angle to harvest to ensure optimum spread.

Figure 9: Straw distribution after wheat harvest in strip tillage (Pflugfelder, 2013).

On light soils, seedbed uniformity was of less concern than on medium or heavy soils and provided that consideration to field operations to the previous crop are taken into account little difficulty was encountered on these soils with regards to crop establishment and yield performance (Morris *et al.*, 2010b).

To improve implement performance on medium and heavy soils a number of alterations to strip tillage implements have been made across Europe. In the UK, Morris *et al.* (2007) studied the area of soil disturbance on a range of soil types; operating parameters of forward speed, tine depth and tine design were investigated. The strip tillage implement used was a Yetter Maverick imported from Yetter Manufacturing, Illinois, USA. The study concluded that the type of tine used was found to be the primary factor in achieving the required volume of disturbance within a narrow zone and that forward speed (between 6.4 and 12.9 km/h) had little impact on the area disturbed regardless of soil type. Implement configuration using various disc designs (smooth discs, wavy or fluted discs) were investigated in BBRO study 07/25 specifically on medium soils where seedbed uniformity was considered to be the primary factor reducing crop performance under strip tillage. In general disc configuration made little apparent improvement to overall performance however it was noted that some smearing occurred particularly when using the smooth discs at higher soil moisture contents (Morris *et al.*, 2010b).

Further improvements in seedbed consolidation in the UK using the Yetter Maverick investigated the use of rolling baskets attached to the rear of the strip tillage implement (Figure 10). These rolling baskets are similar to a crumbler roller but are mounted individually to work just behind the cultivated strip and are concave in shape to keep the soil in a mound. The attached rolling baskets improved overall yield performance using strip tillage by around 6% (Morris, 2011) compared to not having them fitted (see section 3.5 – Impacts of strip tillage on sugar beet yield).

Figure 10: Yetter strip tillage implement fitted with rolling baskets to improve seedbed tilth.

Studies in Belgium have used a Kuhn Striger strip tillage implement manufactured by Kuhn (Figure 11). A winged tine was used to improve seedbed tilth and wavy discs were used to create a narrow disturbed strip. Finger tines to the rear provided consolidation to the strip to prevent the formation of cavities in the strip. These finger tines were removed for all autumn cultivations so that no consolidation occurred at this stage. To ensure consolidation occurred in the spring the finger tines were re-fitted prior to the spring strip tillage operation to assist in seedbed formation.

Figure 11: Kuhn Striger strip tillage implement fitted with winged tines and wavy discs to produce the seedbed and finger tines at the rear to provide consolidation (Roisin, 2014).

Further experimentation in Germany found that by using a prism roller (Figure 12) attached to the front linkage of the tractor and mounting the drill behind a suitable seedbed tilth was produced that resulted in 85-90% plant emergence using strip tillage (Pers comm. Hermann, 2014).

Figure 12: The use of a prism roller can assist in producing a suitable tilth.

Studies in Belgium and Germany (Roisin, 2014; Hermann, 2013) suggested that depth was similarly critical to achieving seedbed uniformity as cultivation timing. Roisin (2014) indicated that on stronger soils cultivation depth below 15cm could adversely affect seedbed uniformity through the creation of cavities (Figure 13). These cavities created pockets in the soil which could lead to uneven depth of sowing or poor seed-to-soil contact leading to uneven crop emergence. Roisin (2014) also noted that increased depth of soil disturbance also increased dirt tare when the sugar beet was harvested. Dirt tare can increase the cost of transporting / cleaning sugar beet at the factory and result in poorer storability of the beet in clamps resulting in higher temperatures and consequently higher sugar losses.

Figure 13: Seedbed cavities (highlighted in red circle) created by excessive depth of strip tillage cultivation to 21cm (Roisin, 2014).

Further soil inspection by Rosin (2014), shown in Figure 14, indicated that the density of soil particles either cultivated to 17cm or 23cm depth using strip tillage was approximately 9.5g/cm^3 and 3.5g/cm^3 respectively. This indicated that the deeper cultivation had created under consolidated soil that may impair sugar beet emergence.

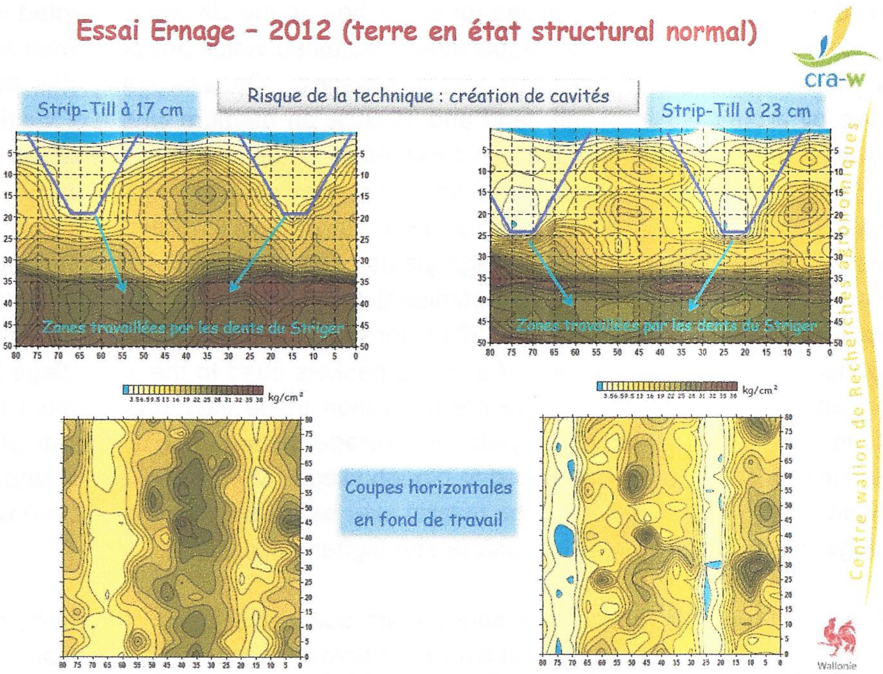

Figure 14: Seedbed uniformity and density comparing soil disturbance to depths of 17cm and 23cm (Roisin, 2014).

Tillage operations alter the rates of soil drying and heating because tillage disturbs the soil surface and increases the number of air pockets in which evaporation occurs, this in time accelerates soil drying and heating (Morris *et al.*, 2010a). Soil temperature and moisture influences the time of seedling germination and growth and under lower disturbance cultivation systems, particularly under direct drilling have resulted in slower crop emergence and reduced growth that can lead to reduced yields. In a German study soil temperatures were monitored using a thermal imaging camera (Figure 15) with results indicating that the strips are comparable to plough tillage although the undisturbed soil between rows were cooler (Pflugfelder, 2013). This was not the case in a UK study where soil temperature was not significantly different between strip tillage and plough tillage either within the strip or between rows (Morris *et al.*, 2010b). In a few cases this was thought to slow sugar beet emergence (Pers comm. Nielsen, 2014) although Morris *et al.* (2007) reported that by full emergence there was little difference in plant populations between strip tillage or plough tillage. Other factors such as moisture availability may have contributed towards the delay in emergence other than soil temperature.

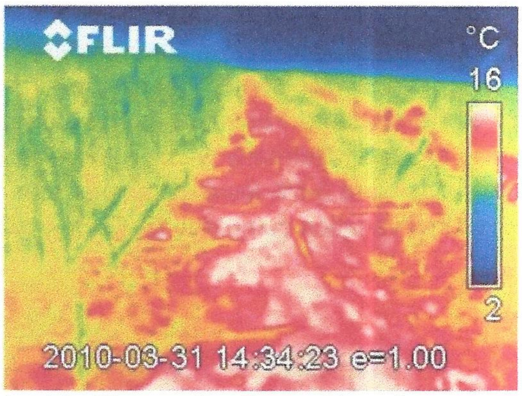

Figure 15: Soil temperature in strip tillage using thermal imaging camera (Pflugfelder, 2013).

3.5 Impacts of strip tillage on sugar beet yield

Adjusted yield responses using strip tillage for sugar beet in the UK are presented in Tables 1 and 2 for sandy loam and sandy clay soils respectively. Adjusted yields are presented as a percentage of the ploughed treatment and averaged across seasons. On average, yields from strip tillage were reduced by around 10% on light land and 10-30% on medium land e.g. yields tended to be more variable on medium soils and this was believed to be as a result of seedbed uniformity (see 3.4 – Quality and uniformity of seedbed section for further details). However, this does hide the specific detail that on light land when using shallow strip tillage (8-10cm) just prior to drilling (late spring) yields were within 2% of plough tillage yields. Greater variation on the medium soil (even when cultivation timing and depth were optimised) resulted in a 8-9% yield reduction. Further experiments carried out in the UK (Morris, 2011) looked at improving yield performance from strip tillage on a medium soil by the addition of a rolling baskets fitted to the strip tillage implement with or without a shallow pre-cultivation. The pre-cultivation made little improvement to yield but the addition of the rolling baskets improved yield, on average, by around 6% (Morris, 2011). However yields were still reduced by 12% compared to plough tillage. Where the use of strip tillage resulted in yields within 2% of the plough tillage the margin over establishment costs (£/ha) was greater due to cost savings made through lower fuel usage and higher work rates.

Table 1: Adjusted yield responses on a sandy loam soil in the United Kingdom; presented as a percentage of the ploughed treatment and averaged across seasons (Morris *et al.*, 2010b).

	Relative yield return (relative to ploughed approach)				
Treatment	**2008**		**2009**		**Avg**
	Shallow	Deep	Shallow	Deep	
Strip tillage – early spring	89	87	87	87	**88**
Strip tillage – late spring	88	88	98	89	**91**
Plough	-	100	-	100	**100**

Table 2: Adjusted yield responses on sandy clay soil in the United Kingdom; presented as a percentage of the ploughed treatment and averaged across seasons (Morris *et al.*, 2010b).

	Relative yield return (relative to ploughed approach)				
Treatment	**2008**		**2009**		**Avg**
	Shallow	Deep	Shallow	Deep	
Strip tillage – early autumn	60	78	-	-	**69**
Strip tillage – late autumn	80	77	-	-	**79**
Strip tillage – early spring	95	92	84	88	**90**
Strip tillage – late spring	84	74	91	79	**82**
Plough	-	100	-	100	**100**

Wider studies from Germany (see Tables 3 and 4) have shown that strip tillage can be comparable to standard tillage approaches although in Germany the standard approach is often using a non-inversion tillage approach due to the risk of soil capping on the silty clay soils. Yields are presented as a percentage of the standard treatment and averaged across seasons. Results in Table 3 from a silty clay soil in southern Germany with a mean annual rainfall of 688mm indicated that, on average, strip tillage yields were 0-5% lower compared to a non-inversion tillage approach although there was some seasonal variation compared to the non-inversion tillage approach.

Table 3: Adjusted yield responses on a silty clay soil in Germany; presented as a percentage of the non-inversion treatment and averaged across seasons (Hermann, 2013).

	Relative yield return (relative to non-inversion tillage approach)				
Treatment	**2008**	**2009**	**2010**	**2011**	**Avg**
Strip tillage	99	96	105	95	**99**
Non-inversion tillage	100	100	100	100	**100**

Further results from a silty clay soil in central Germany, shown in Table 4, indicated that strip tillage resulted in some degree of variation across sites with relative yield return varying from 77 – 102% of the standard treatment. The variability is likely to have been influenced by annual rainfall with Site 1 recording an average annual rainfall of 730mm compared to Site 2 where average annual rainfall was 690mm. The yields from site 2 in central Germany compare very similarly to those from southern Germany with a relative yield return between 94-101%. At both sites 1 and 2, relative yield return was improved by completing a stubble cultivation prior to the strip tillage operation. This was believed to aid surface tilth which aided strip formation and uniformity compared to completing strip tillage cultivations directly into the stubble.

Yield performance across these trial sites in Germany still indicate that strip tillage yields are more variable compared to the standard approach and that the sensitivity to soil conditions when using strip tillage are considered to be one of the critical factors.

Table 4: Adjusted yield responses on a silty clay soil in Germany; presented as a percentage of the standard treatment and averaged across seasons (Demmel *et al.*, 2013).

	Relative yield return (relative to standard approach)							
Treatment	**2010**		**2011**		**2012**		**Avg**	
	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2	Site 1	Site 2
Strip tillage – with tines directly in stubble	86	96	77	90	-	-	**81**	**93**
Strip tillage – with tines after stubble cultivation	97	95	86	98	90	99	**91**	**97**
Strip tillage – with discs directly in stubble	-	95	77	99	-	-	**77**	**97**
Strip tillage – with discs after stubble cultivation	89	117	89	90	95	100	**91**	**102**
Standard cultivation – non-inversion tillage with seedbed preparation	100	100	100	100	100	100	**100**	**100**
Average strip tillage	**91**	**101**	**82**	**94**	**93**	**99**	**85**	**98**
Average standard cultivation	**100**	**100**	**100**	**100**	**100**	**100**	**100**	**100**

Results, presented in Table 5, from a study undertaken in Belgium also indicates that strip tillage performance is generally more variable than that of the standard approach. However, setting the strip tillage implement to cultivate to an optimum depth (11-17cm) resulted in comparable yield performance to that of the standard approach. On average yields attained using strip tillage at 11cm or 17cm resulted in an average yield return of 102% compared to the standard approach. Yield results from strip tillage in nearly all instances increased relative yield return compared to direct drilling indicating that some soil disturbance is necessary to attain yield potential in sugar beet.

Table 5: Adjusted yield responses on a loam soil in Belgium; presented as a percentage of the standard treatment and averaged across sites (Roisin, 2014).

	Relative yield return (relative to standard tillage approach)		
Treatment	**Site 1 - 2012**	**Site 2 - 2012**	**Avg**
Strip tillage – 5cm	96	93	**95**
Strip tillage – 11cm	105	98	**102**
Strip tillage – 17cm	106	99	**102**
Strip tillage – 23cm	105	97	**101**
Average strip tillage	**103**	**97**	**100**
Direct drilling	**98**	**91**	**94**
Standard approach - rotary harrow + roller	**100**	**100**	**100**

3.6 Impacts of strip tillage on weed control

It has long been recognised that changes in cultivation techniques result in changes in both the numbers and species of weeds. Adoption of shallow cultivation tends to result in a greater dominance of grass weeds. Provided that effective weed control is adopted, there is typically a reduction in the numbers of broad-leaved weeds (Froud-Williams *et al.*, 1983). In the absence of strip tillage, much of the ground remains undisturbed and this emphasises changes in weed species and their numbers. Research at NIAB TAG by Nathan Morris indicated that grass weeds became the dominant species and that broad-leaved weed numbers were low in strip tillage. The broad-leaved weeds that can flourish in such an environment are those that germinate on the soil surface, such as mayweeds, and those who seeds are transported by the wind and that can germinate on the soil surface, such as willow-herbs and groundsel. These changes not only have implications for herbicide use and choice but also for potential biodiversity in a crop where broad-leaved weeds in particular appear to be the main source of food.

Field experiments at Sutton Bonington between 1970 and 1974 tested how crop yields were affected by delayed weed control in a sugar beet crop. Losses where weeds were never controlled ranged from 95% where tall growing Fat Hen (*Chenopodium album* L.) predominated to 50% when Chickweed (*Stellaria media* L.) were most involved (Scott *et al.*, 1979). In five of the seven crops examined the latest date at which weeding had to commence to prevent irreversible effects on growth and yield and the earliest date at which weeding could cease without yield loss coincided. For late March/early April sowings this occurred 6 weeks after crop emergence. Sugar beet had generally reached the late singling stage (4–6 true leaves) by the time weeding must have commenced. During the next 6 weeks, final yield was depressed by 120–150kg/ha (1-5%) with each day that weeds were allowed to remain. However, leaf production continued throughout the season and the crop was capable of recovering from early checks caused by weed competition.

Weed beet remain a challenge for beet growers. Whilst control in other crops can be achieved using selective herbicides in sugar beet the weed beets, many of which are of annual habit, are not easily controlled and often compete with the crop (Longden, 1989). An average weed beet produces over 1500 viable seeds and just 1/m^2 reduces yield by 11% (Godsmark, 2012). Around 50% of seeds in the top 20mm will germinate and emerge in spring whereas only 1% of those buried below 100mm will do so (Godsmark, 2012). It is therefore possible that the use of strip tillage may reduce the pressure on weed beet emergence within the crop due to less soil disturbance. However, this should not be at the expense of good crop husbandry by managing weed beet across the rotation. Disadvantages from non-inversion tillage techniques may make remedial soil structural work more difficult and careful soil management is required to achieve good sugar beet seedbeds (Morris, 2013).

The wide rows of sugar beet also increase the potential for mechanical weed control or different herbicide strategies within and between the rows. Whilst mechanical weed control may be practical in some seasons, its potential may be limited in wet seasons. Weeds can often re-root and flourish in these conditions. There are other potential non-herbicide techniques being considered in a review for Defra (Review of literature non chemical pest control for comparative assessment - PS2809). In addition, HDC maintains an interest in non-chemical weed and has recently received a report on electrical weed control in field vegetables (HDC project report SV349).

The wide row spacing of sugar beet may allow for targeted application of herbicides to the crop using simple off the shelf technology as an alternative to using mechanical weed control. Winter oilseed rape is increasingly being grown on wide rows, with 50cm spacing often being accepted as a standard. Conclusions from HGCA study 3652, 'Improving Weed Crops for Effective Weed Control' indicated that 50cm is a row spacing suitable for oilseed rape production.

Research within HGCA project 3605 'New approaches to weed control in oilseed rape' has demonstrated successfully that the use of simple off the shelf technology can be used to direct the application of a total herbicide to a crop grown on wide rows without significant risk of crop damage. By combining even spray nozzles with a shield (whether a basic plate type that could be produced in a farm workshop or a manufactured type like the Garfords shield) can help to mitigate against the risks of crop damage, particularly when glyphosate is applied at later growth stages. Application with the precision positioning systems RTK GPS or vision guidance was found to speed up the application and further limit crop damage. Alternatively the use of a mechanical hoe, coupled with or without Vision Guidance, clearly has benefits on row crops should residual herbicides become unavailable.

The results of this study facilitated further interest and research work within the agrochemical industry on the directed application of contact herbicides to row crops such as winter oilseed rape, vegetables, sugar beet, maize and legumes (where traditional herbicides are being lost). What is often lacking is suitable residue data to support the application of products such as glyphosate applied at early timing. This study is proving useful to support an application for such situations. Within the context of sugar beet if inter-row spraying was used between rows then it would be likely that weed beet could be controlled in the same way that volunteer oilseed rape was controlled between the rows in an oilseed rape crop.

3.7 The role of strip tillage for soil structure and erosion control

Many studies have reported on the benefits that low soil disturbance can have to reduce soil erosion, nutrient movement and benefits of crop residue retention for biodiversity. Mullins (2004) reported that the retention of crop residues within tillage systems has helped to increase the build-up of organic matter close to the soil surface and hence maintain surface stability of the soil. Previous studies from the United States have reported that the retention of crop residue can reduce wind velocity by up to 50% at ground level; thereby potentially reducing the risk of wind erosion particularly on light wind-prone soils. There are suggestions that strip tillage and other low soil disturbance techniques provide a consistent supply of crop residue as a food source encouraging deep burrowing earthworms (Bittman and Kowalenko, 2004) that will allow for an increase in water infiltration. Such changes to soil structure could be particularly beneficial to sugar beet production particularly on light soils prone to wind erosion and drought stress.

The reduction in soil erosion can be of particular benefit on soil types prone to erosion e.g. light sands or silt soils. Studies by Pflugfelder (2013) reported that on a silty clay soil (70% silt, 30% clay) field experiments to simulate rainfall and sediment loss had indicated reductions in soil loss of around 98% where strip tillage had been used compared to plough tillage (Figure 16). This benefit of reduced soil loss was as a consequence of improved water infiltration into the soil and this was possibly related to the straw residue cover between rows protecting the soil surface from direct raindrop impact and therefore reducing the risk of surface sealing that would reduce water movement into the soil.

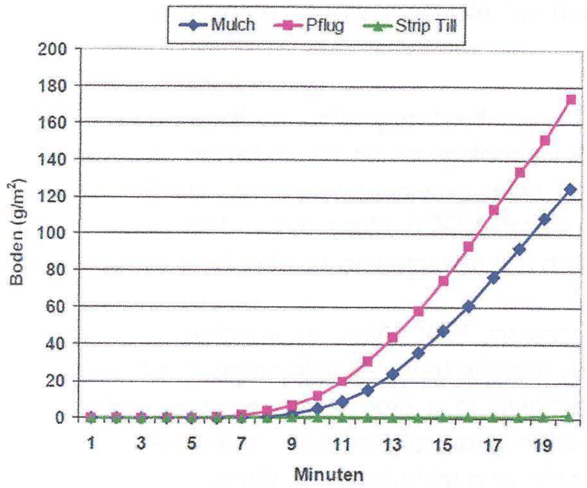

Figure 16: Soil loss (g/m^2) during rainfall simulation experiment under plough tillage, mulch tillage and strip tillage (Pflugfelder, 2013).

A further consequence, reported by researchers, is that of increased bearing capacity, when using strip tillage and this was of particular note during harvesting operations where it was generally noted that the harvesters travelled more easily and left less evidence of wheelings in the field when compared to plough tillage. This is possible as a result of the undisturbed areas between rows having a greater aggregation – soil particles more strongly bound to each other and therefore not being as susceptible to deformation compared to tilled soils with weaker aggregate stability (Morris *et al.*, 2007).

3.8 Integration of strip tillage with alternative management practices

3.8.1 In row fertilisation

Results from recent American studies (Stevens and Eckhoff, 2009) looking at nitrogen fertiliser requirement in relation to strip tillage in sugar beet have not demonstrated any practical implications for nitrogen requirement; specifically this research suggests that while small differences in mineralisation could be expected their practical significance for nitrogen dose requirement was negligible when the nitrogen fertiliser was broadcast. This supports the findings of Morris *et al.* (2010b) which indicated that there were no significant affects on crop growth between strip and plough tillage when nitrogen fertiliser was applied at a rate of 120kg N/ha (as farm standard). Further, benefits of placing nitrogen in bands in sugar beet at the time of sowing, parallel to the seed row, has allowed a reduction in dosage compared to that applied prior to drilling in a separate operation (Draycott, 2006). Therefore, broadcast nitrogen requirement should not vary when comparing ploughing to strip tillage however strip tillage may well lend itself to direct placement, where there is evidence for fertiliser reductions.

Recent development of strip tillage in North America has also involved investigating the precision placement of starter fertiliser (P and K) in sugar beet. Research suggests that this may result in a 20-30% increase in fertiliser uptake efficiency relative to broadcast application (Overstreet, 2009).

In a study undertaken in Germany di-ammonium phosphate (DAP) was placed in the strip as opposed to broadcasting it at the surface (Figure 17). Results suggested an increase in yield relative to broadcasting by an average of 5% although such results in sugar beet are not widely published.

Future development of this in the UK could potentially reduce the overall amount of fertiliser required, and by improving fertiliser uptake efficiency, reduce the risk of nutrients being removed to ground or surface waters and help to mitigate pollution risks.

Figure 17: In row fertilisation using a secondary delivery tube behind the tine (Sander, 2013).

3.8.2 The use of cover crops in strip tillage

The definition of a cover crop can be considered as 'a crop grown primarily for the purpose of protecting and / or improving between periods of regular crop production'. Cover crops are becoming increasingly used in a number of ways (Pers comm. Stobart, 2014) including:

- as a green manure to be incorporated (often to increase organic matter / soil biological activity);
- to improve soil physical characteristics; often to help open up soils and to improve soil structure (either at the surface or even at depth);
- as protection from erosion by wind and water;
- to catch or conserve nutrients that may be lost through leaching or perhaps to improve nutrient availability;
- perturbation to pest and disease cycles or to suppress weeds;
- as supplementary feed (e.g. for livestock, wildlife or perhaps beneficial insects);

A number of studies have shown that cover crops can be an effective measure for tackling diffuse pollution from arable land. Research in the UK and France has shown that cover crops reduced the concentration of nitrate in leachate by about 25-40% (Reeves, 1994; Meisinger *et al.*, 1991). Cover crops have also shown a significant reduction in the risk to soil erosion; experiments undertaken in Canada (Kainz, 1989) indicated that, as a guide, 30% ground cover can reduce run-off by 50% and erosion by 80%. Research carried out within the New Farming Systems programme in the UK has shown that the ongoing use of fodder radish demonstrated a clear positive yield response in the shallow tillage system (tillage restricted to ≤10cm) in 2012. Where the fodder radish wasn't used shallow tillage was the lowest yielding and most variable treatment in the experiment however, where fodder radish was included the treatment was the highest yielding and least variable (Stobart and Morris, 2013). While it is accepted that deep rooting cover crops can deliver bio-cultivation, this may suggest some interaction between the benefits accrued from the use of deep rooted cover crops and the use of a shallow tillage approach.

Factors on farm, such as the fit of particular cover crops with environmental schemes, will impact on their overall value to the system. In addition, it should be remembered that cover cropping systems responses may accrue and deliver ongoing benefits as the systems mature and specific factors, such as the choice of cover crop species (or species mixtures), changes to input costs (e.g. fertiliser and fuel) and additional income from appropriate support schemes, will all influence the costs and financial benefits delivered.

The use of strip tillage and cover crops would seem to be worth further investigation to maximise the potential benefits cover crops may offer, particularly with regards to soil structure, and the protection to soil that cover crops can offer over the autumn and winter period prior to drilling sugar beet in the UK. Work carried out in Germany (Pflugfelder, 2013) has investigated the use of a mustard cover crop (Figure 18) established after harvest in late August to achieve sufficient growth before the onset of cold, wet weather during the autumn / winter period. The mustard was sown after a shallow cultivation to distribute crop residue and create some surface tilth. The cover crop was left to grow until early spring when the cover crop was flailed and then followed by strip tillage cultivation (whilst still green) to a depth of 5-7cm in the same direction to that the cover crop was flailed to ensure trash flow through the strip tillage cultivator. Following the cultivation the cover crop was destroyed by a non-selective herbicide application prior to drilling (Figure 19).

Figure 18: Using a front mounted flail in a mustard cover crop prior to cultivation using strip tillage (Pflugfelder, 2014).

The management of the cover crop in this way prior to cultivation was considered essential to ensure that the material flowed through the strip tillage machine easily without causing blockages. This research had considered that by either destroying or topping the cover crop ahead of strip tillage was not suitable as the material tended to create a mat of material that created blockages with the strip tillage operation. However, under UK conditions, particularly on heavy soils, where the second strip tillage cultivation to freshen up the strip is likely to be carried out nearer to the time of drilling to allow soils time to dry, the destruction of cover crops until after strip tillage cultivations are unlikely to leave a sufficient time for the cover crop to be destroyed prior to drilling. This could cause impedance during the drilling operation although there is a lack of field research to substantiate this. It is possible that specific cover crop species e.g. white mustard which is not frost tolerant (Rosenfeld and Rayns, 2014) may be easier to manage in the spring when following with sugar beet because the cold weather should destroy the mustard over winter leaving less material to impede cultivation and drilling operations. Further work in the UK is required to support cover crop species choice within the context of sugar beet cropping.

Figure 19: Cover crop destroyed and strips ready to be drilled into.

On heavy clay soils in Germany the primary strip tillage cultivation was completed post emergence of the cover crop in early autumn whilst the soil is relatively dry (see Section 3.3 - Cultivation timing on a range of soil types for further information) before the above described method was used for destroying cover crops in the spring. It is essential that GPS-RTK is fitted to machines to ensure that the spring strip tillage operation can be matched to freshen up the soil that has previously been disturbed from the autumn strip tillage operation. To date there is little reported information on the yield benefit that cover crops may have in sugar beet.

3.8.3 Controlled traffic farming and strip tillage

Controlled Traffic Farming (CTF) is a way of managing soil compaction that uses guidance technology to confine all field traffic to the least possible area of permanent traffic lanes (CTF Europe, 2014). CTF is not new but has been made infinitely easier with the advent of satellite guidance systems with repeatable positioning and high level of pass to pass accuracy. In CTF systems traffic is restricted to 10-30% of the total field area compared to current practices where annually traffic is often over 100% of the field area. CTF can significantly reduce input costs (time, fuel and machinery) and increase crop yields by improving soil structure through increased water infiltration and lower soil bulk density allowing for improved rooting capacity of the crop.

Strip tillage may allow the full potential to be achieved through the use of CTF to maximise the potential for restricting field traffic to the least possible area that would allow for improved seedbed uniformity with a reduced risk of random traffic wheelings impacting on strip formation. The integration of CTF and strip tillage may maximise the benefits to soil structure allowing for improved workability of the soil (reducing fuel and labour costs) whilst maintaining soil structure stability that could reduce the risk of soil erosion and diffuse pollution. However, there are challenges to overcome from combining approaches such as the incompatibility of track and row spacing when using strip tillage and the integration of root crops into a CTF system that present a number of challenges particularly at harvesting. Work carried out in Bavaria, Germany indicated that combining CTF and strip tillage in sugar beet increased water infiltration, storage and drainage capabilities of the soils and increased areas left un-trafficked from 24% to 58% compared to a conventional system (Demmel *et al.*, 2011).

4. Guidelines for the implementation of strip tillage for sugar beet

The potential for strip tillage to both reduce cultivation costs and reduce the risk of soil erosion on some soil types have both been shown to allow growers to use an alternative cultivation technique over conventional inversion tillage techniques. However, like with many non-inversion tillage techniques, the attention to detail and greater consideration for the management of field traffic, grass weed management in the rotation and straw residue spread from the combine etc are all required to ensure that strip tillage can be adopted successfully.

To assist growers in deciding where best to use strip tillage a decision support tool has been developed. The flow diagram (Figure 20) details under which conditions strip tillage is most likely to be suited. Consideration should be made to soil type, harvest operations of the previous crop and the potential for grass weeds that are difficult to control in sugar beet. These guidelines should allow growers to make more informed decisions on which to base their cultivation strategy for sugar beet production.

4.1 *Recommendation for cultivations on light soil types (<18% clay content)*

- Leave the crop stubble undisturbed over the autumn / winter period.
- In late winter any weeds should be destroyed using glyphosate to produce a clean, weed-free environment.
- Use GPS (RTK) guidance with the strip tillage implement when cultivating. The strip tillage implement should be set to work to a depth approximately 7-11cm to ensure a fine, firm seedbed is produced 2-4 weeks prior to the drilling operation.
- Use GPS (RTK) guidance with the drill to place seed directly into the centre of the cultivated strip. Ideally a precision drill with disc openers should be used to manage with any remaining surface crop residues.

4.2 *Recommendation for cultivations on medium and heavy soil types (18-45% clay content)*

- Consider a light surface cultivation prior to autumn strip tillage cultivation. This will aid the even spread of crop residues and level the field from any shallow wheelings produced from harvesting operations.
- Consider establishing a cover crop (if required).
- Use GPS (RTK) guidance with the strip tillage implement when cultivating. The strip tillage implement should be set to work to a depth approximately 15-25cm to produce an open, fairly rough seedbed that can weather over winter to produce a fine tilth in the spring
- In late winter the cover crop (if grown) and any weeds should be destroyed using glyphosate to produce a clean, weed-free environment.
- Use GPS (RTK) guidance with the strip tillage implement when cultivating. The strip tillage implement should be set to work to a depth approximately 5-7cm to ensure a fine, firm seedbed is produced 1-2 weeks prior to the drilling operation.
- Use GPS (RTK) guidance with the drill to place seed directly into the centre of the cultivated strip. Ideally a precision drill with disc openers should be used to manage with any remaining surface crop residues.

Recommendation for cultivations on very heavy soil types (>45% clay content)

- Unlikely to be suited to strip tillage.

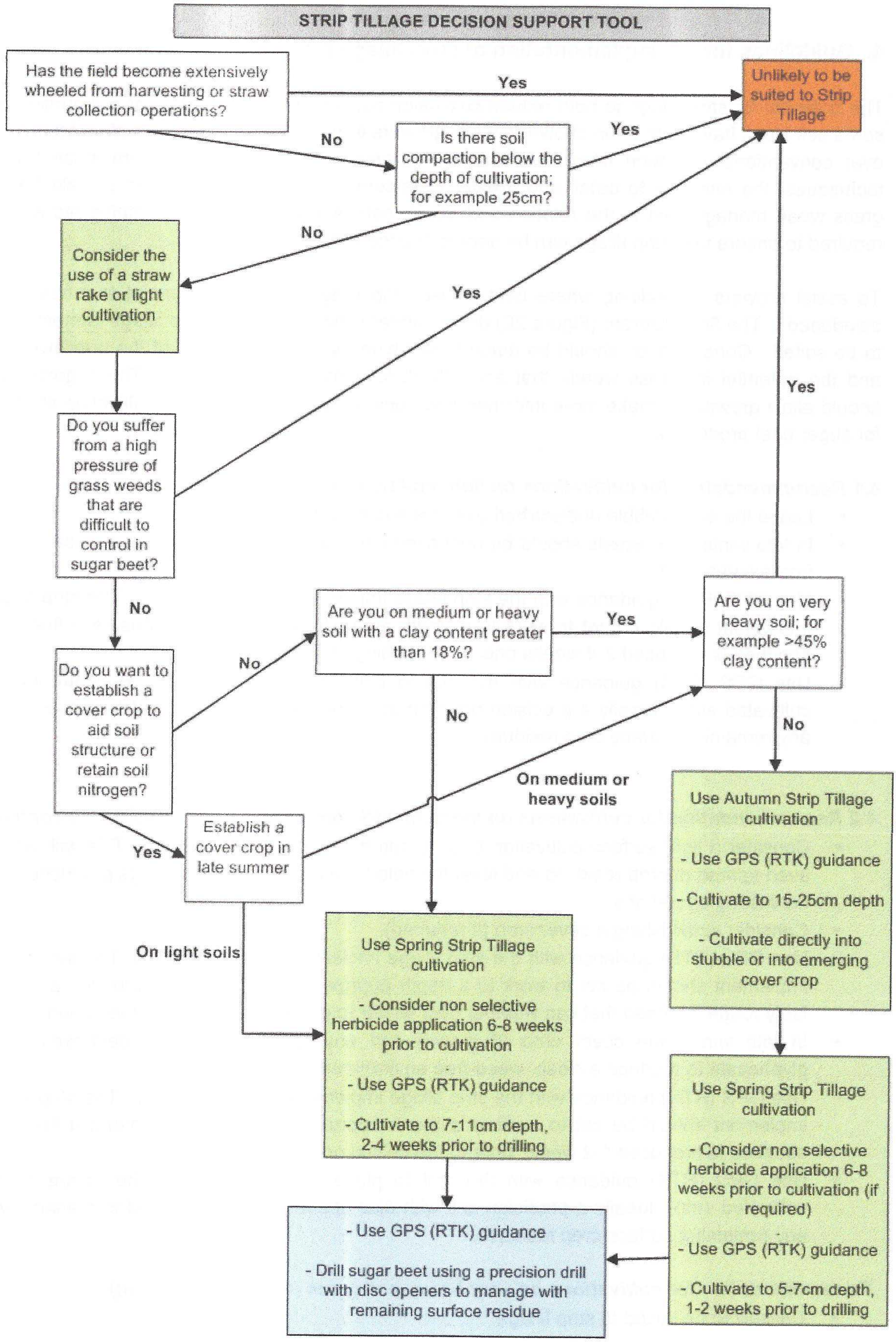

Figure 20: Decision support tool for strip tillage.

5. Conclusions

The use of strip tillage techniques in sugar beet production would potentially allow a number of benefits including reduced cultivation costs (from work rate efficiencies and a reduction in fuel used). Other benefits to the environment include increased biodiversity through the retention of over-wintered stubbles and the reduced soil erosion risk both from wind and water.

Before strip tillage cultivations are chosen for sugar beet it is important to consider if the fields have been extensively wheeled from harvesting or straw collection operations or suffer soil compaction caused below the depth of cultivation (>20cm). Further consideration should be made to particular fields that suffer from a high pressure of grass weeds that are difficult to control in sugar beet. In these situations it is unlikely that these fields will be suited to strip tillage.

To ensure that strip tillage is successfully employed a number of considerations are required including the use of GPS (RTK) guidance, the timeliness of operations and the depth of soil disturbance. These all have an impact on the quality and uniformity of the strips created. The timing of strip tillage operations depend upon soil type; on light soil types a single strip tillage operation is sufficient, however, on medium and heavy soil types (18-45% clay content) it is best to complete strip tillage cultivations at two timings; once in the autumn when the soil is relatively dry and again in the spring to 'freshen up' the strip prior to drilling. In either circumstance drilling is best completed as a separate operation to ensure consistent and uniform seed placement.

From studies in the UK and across Europe yield performance using strip tillage indicates that strip tillage yields tend to be more variable compared to the standard approach particularly on medium and heavy soils. The sensitivity of strip tillage to soil conditions is considered to be one of the critical factors.

Whilst yields tend to be slightly lower than standard cultivation approaches there are a number of significant benefits that strip tillage may provide. Reductions in costs are possible through increased speed of working and this should improve the timeliness of such operations. Less soil disturbance generally reduces the emergence of broad leaved weeds. There is some evidence to suggest that strip tillage may reduce the pressure on weed beet emergence within the crop due less soil disturbance although further research to quantify this would seem prudent.

Further benefits of integrating strip tillage with the use of cover crops or fertiliser placement would seem to be of significant interest. Cover crops could enable improved soil physical characteristics; capture nitrogen over winter and allow opportunities to increase the biological activity within the soil that could enhance nutrient availability to the sugar beet crop. Currently there is little information available on the specific species of cover crop most suited to the autumn / winter period prior to sugar beet that does not affect the spring cultivation or drilling operations. Also there is little available data at present to quantify the yield results in sugar beet following a cover crop. The potential to improve fertiliser use efficiency through targeting placement within row could allow for potential saving in fertiliser costs thus making the economics of using strip tillage more credible. However further research to quantify this in the UK would seem prudent.

6. Further areas for research

Further studies are considered necessary to integrate the use of strip tillage with cover crops. Cover crops are becoming increasingly used to improve soil physical characteristics; to protect soil from erosion by wind and water and to catch or conserve nutrients that may be lost through leaching or perhaps to improve nutrient availability. However, there are many different species of cover crops suited to different purposes and are likely to require different management approaches. The opportunities of strip tillage to offer improved environmental protection including the reduction in soil and water erosion could be enhanced by the use of cover crops that could enable improved soil physical characteristics; capture nitrogen over winter and allow opportunities to increase the biological activity within the soil that could enhance nutrient availability to the sugar beet crop. Initial results from the Wensum DTC project (Defra Project WQ0212) indicated that the seven fields with a cover crop had nitrate concentrations one or two orders of magnitude lower than those fields where no cover crop was grown.

To this end, a programme of research should be initiated that would consider a range of cover crop species (to consider what the purpose of the cover crop is for e.g. soil structure and/or nutrient capture) within a range of strip tillage approaches e.g. cultivation timing to investigate the potential benefits of cover crops and explore the destruction of cover crop species prior to spring strip tillage / drilling to ensure that cover crops do not interfere with this process. The specific species of cover crop is likely to be different to those chosen in France or Germany due to the climatic differences (e.g. periods of frost) that would alter how cover crops are managed.

Further studies would also be considered beneficial for investigating the placement of fertiliser in sugar beet rather than by surface broadcasting fertiliser to the total field area. Earlier studies on the placement of nitrogen fertiliser in sugar beet suggested that whilst the total crop requirement (120kg N/ha) did not significantly vary between plough tillage and strip tillage the opportunity to place fertiliser in a band could provide opportunities for savings to be made through a reduction in the total quantity of fertiliser required. There may also be an opportunity to place phosphrous (P) and potassium (K) in bands using strip tillage and results from a study in Germany has shown, on average, a yield response of around 5% compared to broadcast. Previous studies in America have also reported that P and K fertiliser uptake efficiency may be improved by around 20-30% if placed rather than broadcast. However, this would need to be investigated within the context of UK production systems and climatic conditions to quantify the benefits.

Benefits of using strip tillage may also assist in the control of weeds, particularly through lower soil disturbance and through the potential use of integrating strip tillage with inter-row weed control. In this way it may be possible to manage weed beet between the rows through the use of glyphosate although this would need further study to quantify the reductions in weed beet populations.

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References

Anon. (2014) Sugar Beet Reference Book 2014. British Beet Research Organisation, Norwich.

Billen N., Übelhör A., Witte I., Ziegenhagel H., Truckses T. and Herrmann W. (2013) Effect of strip tillage on soil water and water erosion. KTBL Technical Discussion Group; 15-16th May 2013. University of Hohenheim, Germany.

Bittman S. and Kowalenko, CG (2004) Advanced Silage Corn Management. Pacific Field Corn Association, Agassiz.

Carter A., Jordan V. and Stride C. (2003) *A guide to managing crop establishment.* Soil Management Initiative, Chester.

CTF Europe (2014) What is CTF? Controlled Traffic Farming Europe Ltd, UK. Available from http://www.controlledtrafficfarming.com/Home/Default.aspx#

Davies B. and Finney B. (2002) *Reduced cultivations for cereals: Research, development and advisory needs under changing economic circumstances.* Home Grown Cereals Authority, London. Research Review No. 48

Defra Project WQ0212. Demonstration Test Catchments: Catchment scale testing of measures to mitigate diffuse agricultural pollution on the Wensum.

Demmel M., Brandhuber R., Mueller M., Marx M. and Kirchmeier H. (2011) Research on Controlled Traffic Farming and Strip Tillage in Bavaria. Presneted at a Workshop on controlled traffic farming and strip tillage – combining precision farming technology with field traffic and tillage strategies; May 25th – 26th, 2011.

Draycott P. (Ed.) (2006) Sugar Beet. Blackwell Publishing: Oxford.

Ecclestone P. (2014) Strip tillage for sugar beet: an initial look. *British Sugar Beet Review*, **82** (1): 26-28.

Froud-Williams RJ., Drennan DSH., Chancellor, RJ. (1983) Influence of Cultivation Regime on Weed Floras of Arable Cropping Systems. *Journal of Applied Ecology* **20** (1): 187-197.

Godsmark D. (2012) Weed beet – the battle must go on. *British Sugar Beet Review*, **80** (3): 14-15.

HDC Research Project FV 307 / HortLINK 0183 Minimising environmental impact of weed control in vegetables by weed detection and spot herbicide application.

Herrmann W., Bauer B. and Bischoff, B. (2012) Strip till – strip to success. DLG-Verlag, Germany.

Kainz M. (1989) Runoff, erosion and Sugar beet yields in conventional and mulched cultivation. Results of the 1988 experiment. Soil Technol. Ser. **1**: 103-114.

Knight, S., Miller, P. and Orson, J. (2009) An up-to-date cost / benefit analysis of precision farming techniques to guide growers of cereals and oilseeds. HGCA Research Review 71. London: Home Grown Cereals Authority.

Longden, PC (1989) *Effects of increasing weed-beet density on sugar beet yield and quality. Annals of Applied Biology*, **114**: 527-532.

Meisinger JJ, Hargrove WL, Mikkelsen RB, Williams JR, Benson WV. (1991) Effect of cover crops on groundwater quality. In *Cover Crops for Clean Water*, pp. 57–68. Ed. W L Hargrove. Ankeny, IA: Soil and Water Conservation Society.

Morris NL., Miller PCH, Orson JH. and Froud-Williams RJ. (2007) *Soil disturbed when using a strip tillage implement under a range of soil types and operating parameters and the effects on sugar beet establishment.* Soil Use and Management. **23**: 428-436.

Morris NL. (2008) The establishment of arable crops in UK cereal stubbles using strip tillage, PhD Thesis

Morris N. (2009) Strip tillage – A new method in sugar beet cultivation. *British Sugar Beet Review*, **77** (1): 26-27.

Morris N. (2011) *The development of strip tillage to improve sugar beet performance on medium soils.* NIAB TAG Landmark Bulletin. (Issue 8) December 2011

Morris N. (2013) Weed beet – by the scruff of its neck! *British Sugar Beet Review*, **81** (4): 23-26

Morris N., Miller, PCH., Orson, J. and Froud-Williams, RJ. (2010a) *The adoption of non-inversion tillage systems in the United Kingdom and the agronomic impact on soil, crops and the environment—A review.* Soil & Tillage Research. **108**: 1-15.

Morris, NL., Stobart, RM. and Burks, E. (2010b) Development of strip tillage techniques in sugar beet production. BBRO report 07/25. BBRO, Norwich.

Mullins,C. (1991) Physical properties of soils in urban areas, In Bullock P. & Gregory, PJ. (eds.) Soils in the urban environment. pp 87-118. Blackwell Science, Oxford.

Mullins CE., (2004) Soil problems worldwide and their solution: lessons for UK agriculture. Conference at the Managing soil and roots for profitable production: Focusing on the agronomic, environmental and economic impact of cultivation systems and establishment methods., London.

Overstreet L. (2009) Strip tillage for sugar beet production. *International Sugar Journal.* **111**: 292-304.

Pflugfelder M. (2013) Strip tillage – strengths and weaknesses in practice. KTBL Technical Discussion Group; 15-16th May 2013. University of Hohenheim, Germany.

Reeves DW. (1994) Cover crops and rotations. In *Crops Residue Management*, pp. 125–172. Ed. J L Hatfield and B A Stewart. Advances in Soil Science. Boca Raton, FL: Lewis Publications, CRC Press.

Roisin C. (2014) Strip tillage planting in sugar beet. Presentation from Walloon Agricultural Research Centre, Department of Agriculture and Natural Environment - Unit Soil Fertility and Water Protection. www.cra.wallonie.be

Rosenfeld A. and Rayns, F. (2014) Sort out your soil – A practical guide to green manures. Cotswold Grass Seeds Direct. Available at:
https://www.cotswoldseeds.com/files/cotswoldseeds/Cotswold_Green_Manures_final.pdf

Scott RK, Wilcockson SJ and Moisey FR (1979) *The effects of time of weed removal on growth and yield of sugar beet. Journal of Agricultural Science*, **93**: 693-709.

Stevens WB. and Eckhoff J. (2009) Managing nitrogen inputs to optimize grower returns [meeting abstract], 31-32.

Stobart RM. and Morris NL. (2013) *Approaches to cover cropping and the impact on soils and farming systems. Aspects of Applied Biology* ***121****, Rethinking Agricultural Systems in the UK*, pp. 43-50