BBRO 07/25: Development of strip tillage techniques in sugar beet production

NL Morris
The Arable Group

RM Stobart
The Arable Group

E Burks
British Sugar plc

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Summary

Strip tillage is a non-inversion technique that has been widely adopted in some areas of the United States for growing row crops e.g. maize and sugar beet. This system cultivates narrow bands of soil directly into crop stubble, thus reducing the total area of cultivated soil allowing areas of undisturbed soil to be left. The system can reduce the risk of soil and wind erosion and, as a non-inversion tillage technique, improve soil structural properties through the retention of crop residues. More recent strip tillage designs are based on a non-powered disc and tine configuration running at depths between approximately 8 cm and 17 cm that can produce a seedbed in one pass. The system can allow for a reduction in the number of cultivation operations compared to conventional plough tillage with the impact of reducing costs associated with cultivation (fuel and labour). With relatively high operating speeds, higher work rates can be achieved compared to conventional plough systems improving the timeliness of field operations.

Study 07/25 has looked at the potential for strip tillage to be used in sugar beet production in the United Kingdom and has examined the technique on two soil types, a medium sandy clay loam and a light sandy soil, over two seasons. An initial study to report on the soil engaging mechanism and strip creation of both a Claydon drill and a Yetter strip tillage machine found the Yetter produced more appropriate seedbed conditions in terms of the area disturbed and the cohesion of the soil, further, that substantial modification to the Claydon drill would be required to achieve a similar result. Therefore it was decided that all trial plot work would continue to use the Yetter in this study. On the light sand soil the Yetter performed well producing yields that were comparable to ploughing, particularly in the second season where final plant populations were very similar to that of the plough. Very few differences in root quality (fanginess or root impurities) were apparent between systems on the light soil type resulting in no adverse affect on sugar yield between systems. On the medium soil type performance was more variable when using strip tillage although there was a definite response to cultivation timing, which although inconsistent from season to season, suggested that spring timing produced improved crop establishment and therefore yield. No consistent trend was apparent when changing between disc configurations although yield results from year two suggest that the semi-aggressive discs improved performance compared to smooth or aggressive discs.

It would appear that as a technique strip tillage could offer growers on light land soils an alternative method for establishing sugar beet, whereby both crop establishment costs and the environmental impact of cropping (through wind and soil erosion) could be reduced. On the medium soil type results have been more variable and are likely to be related to soil conditions at the time of cultivation and seedbed consolidation. On this note it would be beneficial to continue the development of this system for medium soils to modify the implement to ensure improved seedbed consolidation / tilth. It is believed that methods of improving seedbed consolidation behind the strip tillage implement would greatly improve the establishment of the sugar beet and allow for comparable performance to plough tillage. Relatively small modifications that could improve strip tillage performance include the addition of a crumbler / tyre packer to enhance seedbed consolidation behind the primary discs or by fitting finger tines on a simple toolbar to be mounted ahead of the drill unit that would freshen up the seedbed (this may be necessary for autumn cultivation timings where the soil has slumped over-winter).

Introduction

Strip tillage has been used extensively in North American row crop production systems including maize, soya beans, cotton and sugar beet (Morrison 2002) for the last decade. Recent changes in strip tillage implement design have seen a change from powered `rotary` implements to non-powered tine and disc implements, that are potentially suitable to work in a wider range of soil and cropping conditions than earlier designs.

Strip tillage involves cultivating a strip sufficient only to establish the crop and is particularly suited to row crops such as sugar beet. The implement works directly into crop stubbles and cultivates a narrow band of soil suitable for drilling seed into. Cultivation occurs on approximately 40% of the field area leaving 60% undisturbed with the retention of crop stubble seen as advantageous in terms of reducing soil erosion risk and offering the potential for over-wintered stubbles for environmental stewardship. The benefit of retaining crop residue between rows has been reported in studies that suggest strip tillage systems can reduce wind velocity at the soil surface by 50% (Overstreet, 2009) and consequently can greatly reduce the risk of wind erosion.

The design and function of the implement allows operation at relatively high forward speeds that assist with crop residue flow away from the cultivated strip. A recent Iranian study reported that a star wheel attachment can cope well with a range of straw residue conditions (representing both chopped and baled) and can remove up to 70% within the row compared to not using one (Raoufat and Matbooei, 2007). Working speed and minimising the area of soil cultivated achieves significant cost savings in terms of both labour and fuel. Studies have suggested that fuel use using a strip tillage implement varies depending on machine configuration but can typically reduce fuel consumption by 33% to 50% compared to full width tillage (Overstreet, 2009). Most modern strip tillage implements can be operated at speeds of 5-8 km h^{-1} with a recent study from the UK reporting that forward speeds from 6 to 13 km h^{-1} made little difference to the area disturbed suggesting that, other than requiring an increase in draught requirement, faster operating speeds could be used to increase implement work rates (Morris *et al*, 2007). In a recent U.S. study Stevens and Iverson (2009) have suggested that implement configuration and the degree of cultivation, consolidation and seed-soil contact have been identified as being important, particularly for small seeded crops like sugar beet.

This project used a Yetter 2984 Series Generation 2 Maverick Opener purchased from Yetter Manufacturing, Illionois, USA. The strip tillage implement uses individual “units” that are bolted directly to the toolbar using clamp bracket castings. Each “unit” consists of a number of components (see Figure 1) including a parallel sprung linkage, star wheels, opening disc coulter, depth skid, cultivation tine and closing discs that are fully adjustable or inter-changeable allowing for adjustment to suit particular conditions. A number of recent studies in the United States and Canada (Overstreet, 2009, Overstreet *et al*., 2008 and Stevens and Iverson, 2009) have concluded that the use of a strip tillage implement in sugar beet production can result in sugar beet yields that do not differ from conventionally grown sugar beet, provided that seedbed tilth conditions resulted in good seed to soil contact to facilitate even crop establishment. Study 07/25 sought to determine whether or not such an implement could be used successfully for sugar beet cropping in the United Kingdom and under what conditions (soil type, cultivation timing and implement configuration) it would be most suitable to maintain output to that similar to a conventional plough tillage approach.

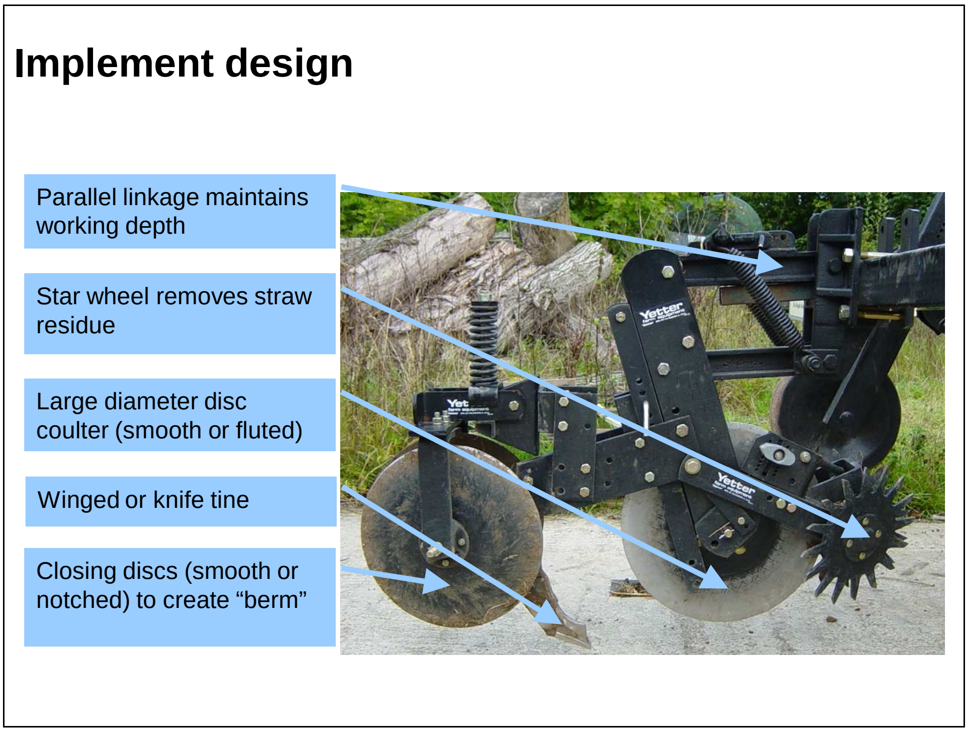


Figure 1: Implement components on strip tillage implements.

The main aim of the present study was to:

> Evaluate the potential for strip tillage in sugar beet production in England and to develop guidelines for its potential adoption.

The objectives were as follows:

(a) To evaluate the Claydon drill soil engaging mechanism (and possible alternative mechanisms on one pass narrow row drills) as a possible method of creating strips without having to purchase specialist strip tillage cultivators.
(b) To match a Yetter four row strip tillage machine and also the Claydon drill (or alternative) to a four row precision drill unit.
(c) To establish two field experiments/year, one on the medium loam at TAG Morley and one on a sand soil near Thetford.
(d) To measure soil strength, temperature of the seedbeds, rate of crop establishment and canopy development, yield and root shape.
(e) To analyse results and review treatments.

Approaches

Preliminary evaluation of cultivation mechanisms suitable for strip tillage

A preliminary study to determine the suitability of cultivation mechanisms for strip tillage was carried out in Autumn 2007 on a light sandy loam soil at Hockering, Norfolk. A non-replicated field block study in a wheat stubble field was used for cultivating strips using both a Claydon drill and a Yetter Maverick strip tillage implement. Implement settings used were agreed as suitable for the cultivation of sugar beet (e.g. to create a seedbed that is level, fine and firm with sufficient surface tilth and consolidation in the upper profile for good seed-soil contact). To quantify the performance of both machines a series of soil measurements were made that included:

- Shear vane – To quantify the cohesive force of the soil.
- Soil laser profile meter – To determine the area of soil disturbed.
- Plaster of Paris casts of disturbed soil.

These assessments were used to determine the suitability of implements for strip tillage cultivations that would be used for field plot trial work in year 2 (2008) and year 3 (2009).

Field experiments to evaluate strip tillage

A series of field experiments were undertaken in two seasons; 2008 and 2009 on both light (Roudham, Norfolk) and medium (Morley, Norfolk) soil types. At Roudham the soil is classified as a stony, sandy loam (Freckenham series) and Morley is classified as a sandy clay loam over clay (Burlingham series). These experiments employed a series of treatments using strip tillage (with treatments varying according to adjustments made for cultivation depth and disc configuration) compared to conventional plough tillage (ploughed at 25 cm followed by a power harrow). Disc configuration on the strip tillage implement included the use of smooth discs, using both a smooth disc coulter and smooth closing discs; semi-aggressive discs that used a fluted disc coulter and smooth closing discs or aggressive discs that used a fluted disc coulter and notched closing discs. These treatments were established at a range of cultivation timings through the year including early and late autumn (medium soil type only) and early and late spring timings (medium soil and light soil types). After Year 2 results were analysed and a revised treatment list was agreed upon to take forward in Year 3. Detailed trial information and outline methods are summarised in Tables 1 and 2.

Sites were selected based on specific soil types required for this project; soil samples taken from these sites were analysed for mineral and nutrient status (see Appendix A). Specific cultivations were established at the sites according to protocol using farm machinery suited to small plot work. All other field operations and crop inputs (e.g. fertiliser, herbicides and fungicides) were applied as farm standard by the host farmer and applied according to the commercial farm crop (see Appendix E for all inputs and timings). Due to the presence of free living nematodes at the sandy soil type site (Roudham) all drilling was completed with the additional application of a nematicide (oxamyl) applied with the sugar beet seed.

Data interpretation from this project came from both direct assessments that were made on a range of soil physical properties (e.g. soil temperature, soil penetration, shear vane strength) and agronomic parameters (e.g. crop establishment and plant population, canopy growth and light interception, crop yield, root shape, sugar content and root impurities) and from derived financial performance (e.g. output minus cultivation costs) for each scenario. These assessments seek to identify factors that may alter under a change in cultivation regime and will help to provide an understanding of suitable conditions and requirements for strip tillage.

Table 1. Summary of trial information (Roudham, 2008 and 2009).

Trial Id	**BV08-002**	**BV09-002**
Location	Keepers Piece, Roudham Farms, Roudham, Norwich, Norfolk	Field Twelve, Roudham Farms, Roudham, Norwich, Norfolk
Cropping	Sugar beet cv Goya	Sugar beet cv Bobcat
Drilling date	1st April 2008	7th April 2009
Seed rate	Approx 1.18 units/ha	Approx 1.18 units/ha
Harvest date	19th November 2008	7th December 2009
Cultivations	*Shallow strip tillage (c. 10 cm)* – Yetter strip tillage (using smooth discs only). *Deep strip tillage (c. 15-17 cm)* - Yetter strip tillage (using smooth discs only). *Plough* - ploughed followed by power harrow prior to drilling. All cultivation timings vary according to treatment (see Appendix E for specific timings)	*Shallow strip tillage (c.8-10 cm)* – Yetter strip tillage (using smooth and aggressive discs). *Deep strip tillage (c. 15-17 cm)* - Yetter strip tillage (using smooth and aggressive discs). *Plough* - ploughed followed by power harrow prior to drilling. All cultivation timings vary according to treatment (see Appendix E for specific timings)
Inputs& Husbandry	Appropriate to site standard.	Appropriate to site standard.
Trial design *No. of treatments / replicates* *Plot size* *Analysis*	Factorial 6 treatments 6 replicates 2 m x 24 m approx. ANOVA with LSD quoted at P = 0.05	Factorial 8 treatments 4 replicates 2 m x 24 m approx. ANOVA with LSD quoted at P = 0.05

Table 2. Summary of trial information (Morley, 2008 and 2009).

Trial Id	**BV08-001**	**BV09-001**
Location	Sixteen Acres, Manor Farm, Morley, Wymondham, Norfolk	Bullswood, Manor Farm, Morley, Wymondham, Norfolk
Cropping	Sugar beet cv Goya	Sugar beet cv Bobcat
Drilling date	9th April 2008	7th April 2009
Seed rate	Approx 1.18 units/ha	Approx 1.33 units/ha
Harvest date	16th October 2008	2nd December 2009
Cultivations	*Shallow strip tillage (c. 8-10 cm)* – Yetter strip tillage (using smooth discs only). *Deep strip tillage (c. 15-17 cm)* - Yetter strip tillage (using smooth discs only). *Plough* - ploughed followed by power harrow prior to drilling. All cultivation timings vary according to treatment (see Appendix E for specific timings)	*Shallow strip tillage (c. 8-10 cm)* – Yetter strip tillage (using smooth, semi-aggressive and aggressive discs). *Deep strip tillage (c. 15-17 cm)* - Yetter strip tillage (using smooth, semi-aggressive and aggressive discs). *Plough* - ploughed followed by power harrow prior to drilling. All cultivation timings vary according to treatment (see Appendix E for specific timings)
Inputs& Husbandry	Appropriate to site standard.	Appropriate to site standard.
Trial design *No. of treatments / replicates* *Plot size* *Analysis*	Factorial 12 treatments 4 replicates 2 m x 24 m approx. ANOVA with LSD quoted at P = 0.05	Factorial 14 treatments 4 replicates 2 m x 24 m approx. ANOVA with LSD quoted at P = 0.05

Results and discussion

Cultivation mechanisms suitable for strip tillage

A series of soil measurements were taken to compare the suitability of either a Claydon Drill or a Yetter Maverick strip tillage system. As indicated in Figure 2 results from using a laser profile meter to determine the area of soil disturbed using both machines suggest that the Claydon drill cultivated a narrower zone of soil compared to the Yetter Maverick. This can be seen clearly in Figure 3 where a plaster cast was taken from the area where soil had been disturbed by carefully removing the loosened soil. The Claydon cast had a more V-shaped profile with a much narrower groove at depth. This compares to the Yetter Maverick where a U-shaped area of soil disturbance occurred resulting in a wider groove at depth.

When comparing the cohesive resistance of the soil both at the soil surface and at 10 cm, Figure 4 indicates that, whilst the surface cohesion is similar between both cultivation systems (3-6 MPa), at depth the Claydon resulted in a much greater cohesive force (15 MPa) than the Yetter Maverick (5 MPa). This illustrates the apparent effect that the narrower band of cultivated soil created by the Claydon drill has on the soil structure and tilth created.

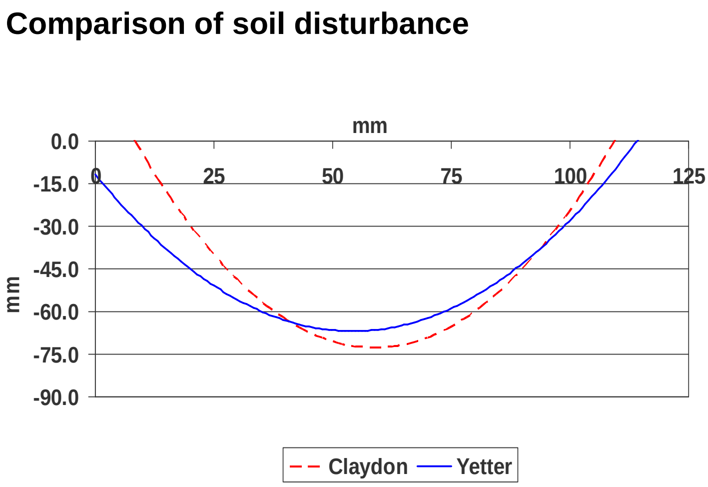


Figure 2: Comparison of a Yetter strip tillage implement with a Claydon drill and the area of soil disturbed.

Comparison of soil disturbance

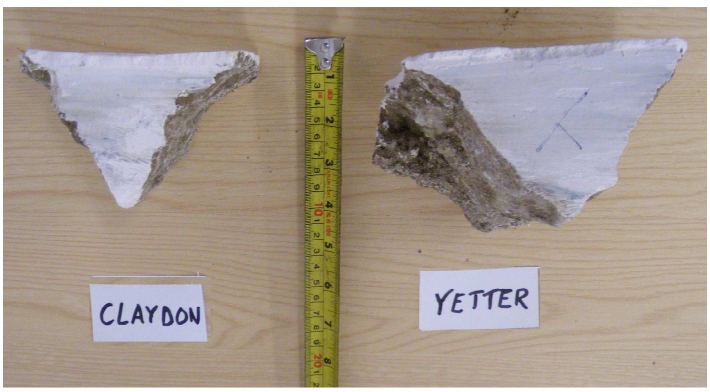


Figure 3: Comparison of a Yetter strip tillage implement with a Claydon drill and the area of soil disturbed as indicated by plaster casts.

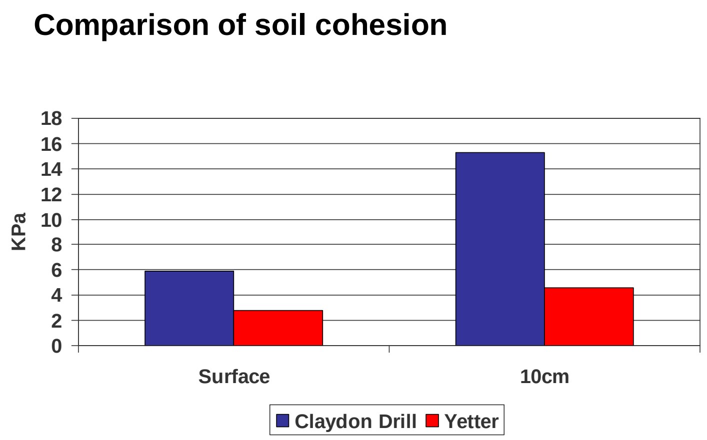


Figure 4: Comparison of a Yetter strip tillage implement with a Claydon drill and the cohesion of the soil.

Observations also indicate that at present the Claydon drill tine configuration left the soil surface with less well defined strips compared to that of the Yetter strip tillage machine. This mixing of straw residue when using the Claydon drill was believed to be unsuitable for good seed-soil contact required by the small seeded sugar beet crop. From the assessments on the area of soil disturbance and soil cohesion it was decided that the Claydon drill would require substantial modification, particularly for the handling of straw residue within the row and the adjustment of row width suitable for sugar beet. It was therefore decided that this project would use the Yetter Maverick for all strip tillage cultivations in the field trial plot experiments.

Strip tillage for light land sugar beet production

Cultivations and drilling

Primary cultivations (plough or strip tillage) occurred during early spring (early-mid February) and late spring (early April) in both 2008 and 2009 seasons and were completed in good conditions (soil moisture recorded at 9-10% in both seasons). Plough cultivations were followed with a power harrow to produce a seedbed followed by drilling, whilst strip tillage was followed by the drilling operation only. The light soil type, which is free-draining produced a good, fine seedbed in both seasons. All drilling was completed on a single day (either 1st April 2008 or 7th April 2009) to achieve a target plant population of 80,000 to 100,000 plants/ha. Crop emergence followed within 10-14 days of drilling.

Soil physical properties

Soil temperature; During 2008 soil temperature was monitored at 5 cm both within and between rows. A comparison of the Yetter (shallow or deep) and the plough at the early spring cultivation timing indicated no consistent differences in soil temperature (between early April and late May) in any treatment (data shown in Appendix B).

Soil penetrometer and shear vane measurements; Soil penetration (to measure the resistance encountered by roots during growth) was recorded during early establishment of the sugar beet crop in both 2008 and 2009. Measurements in relation to cultivation method are presented in Figures 5 and 6 (within row and between row respectively) for the 2008 season; further results (2009 season) can be found in Appendix B. Differences presented in Figure 5, as measured within row, are relatively small suggesting that cultivation using the Yetter, at either cultivation depth, was creating similar loosening of the soil compared to the plough. As would be expected resistance between row (Figure 6) indicated that leaving the soil undisturbed between rows when using the Yetter increased soil strength compared to the plough; in 2009 this effect was more pronounced but followed the same trend (see Appendix B).

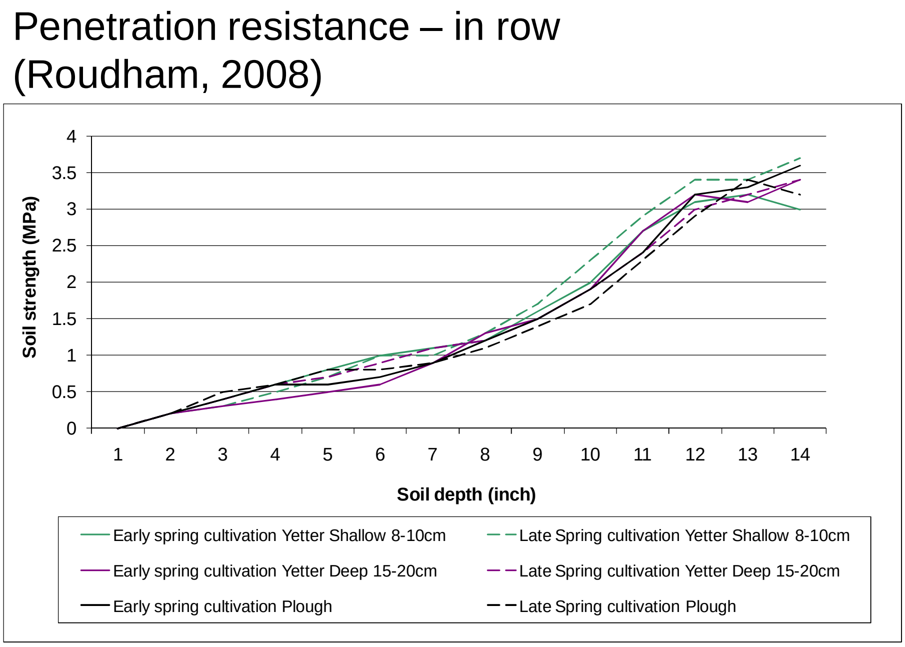


Figure 5: Effect of cultivation on soil penetrometer resistance within rows (Roudham, 2008).

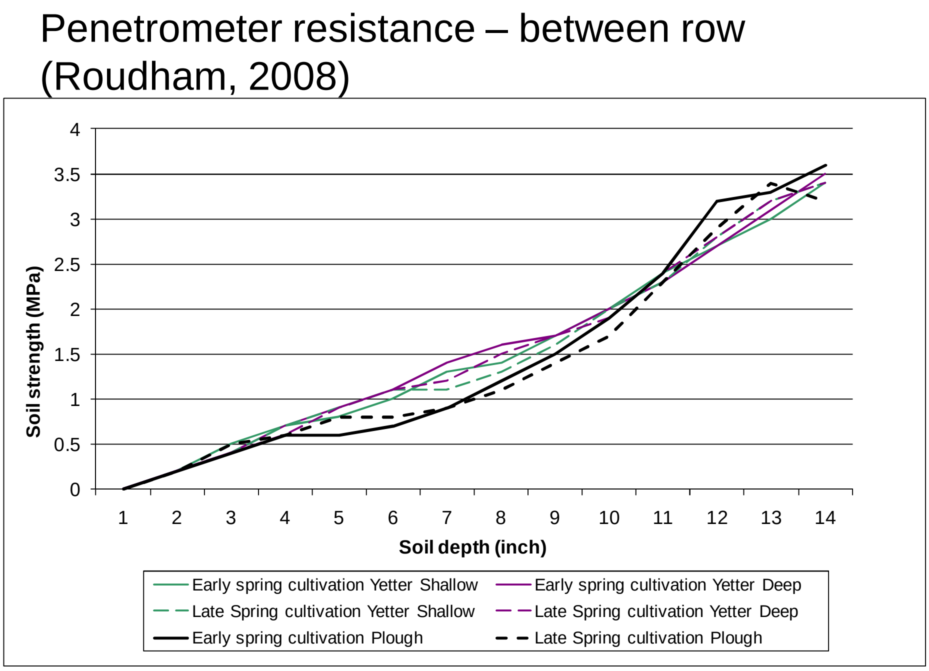
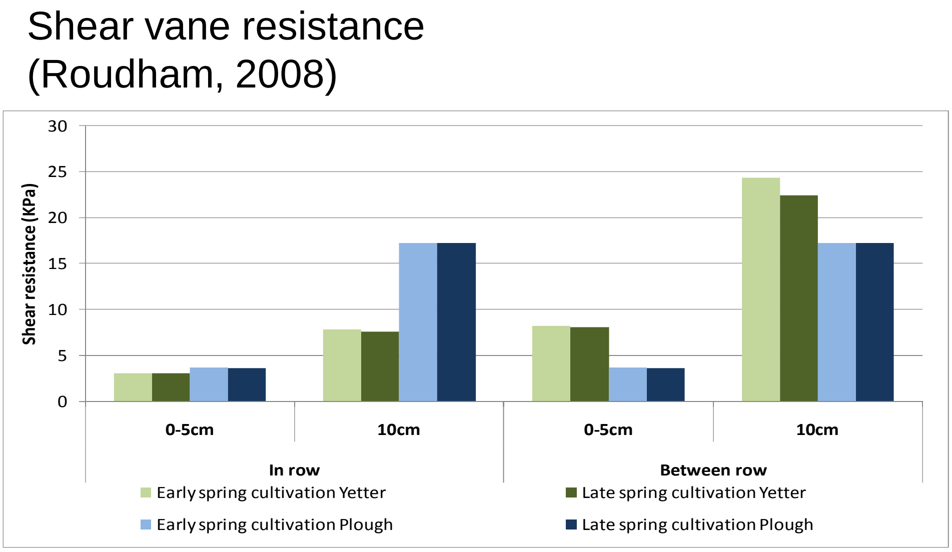


Figure 6: Effect of cultivation on soil penetrometer resistance between rows (Roudham, 2008).

The effect of cultivation on soil cohesion using a shear vane meter, both within and between rows, is shown in Figure 7 (2008) and Appendix B (2009). Surface cohesion (5 cm) indicated similar resistance within row across all cultivation treatments and cultivation timings (specific Yetter depths not included as the differences were small). However, measurements at 10 cm resulted in lower resistance in all strip tillage treatments compared to the plough and would suggest that seedbed consolidation was not achieved to the same degree to that of plough tillage. In 2009 (see Appendix B) the use of an aggressive disc at the earlier cultivation timing indicated a small but noticeable change in cohesion at 10 cm depth suggesting some improvement to seedbed consolidation had been achieved. Due to the lack of soil disturbance between rows when using the Yetter there was some apparent increase in soil cohesion (both in 2008 and 2009) compared to the plough.



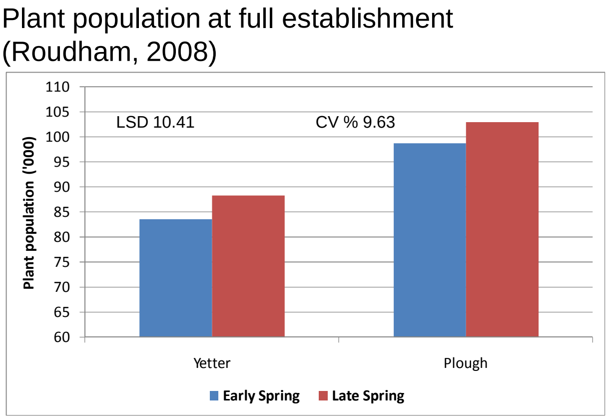
LSD	0-5cm	10 cm
Within row	0.7	2.1
Between row	1.9	3.5

CV %	0-5cm	10 cm
Within row	18.9	16.3
Between row	18.9	12.0

Figure 7: Effect of cultivation on soil cohesion within and between rows (Roudham, 2008).

Crop establishment and growth

Plant population; Strip tillage resulted in final plant populations that were significantly lower than the plough in 2008 (see Figure 8). This slightly poorer establishment is probably due to the impact of reduced seedbed consolidation (as indicated by shear vane measurements) compared to the plough. However, it must be emphasised that the final plant populations achieved with both the Yetter and the plough are between 80,000 and 100,000 plants/ha i.e. optimum to achieve a high yield (BBRO Project 06/05).



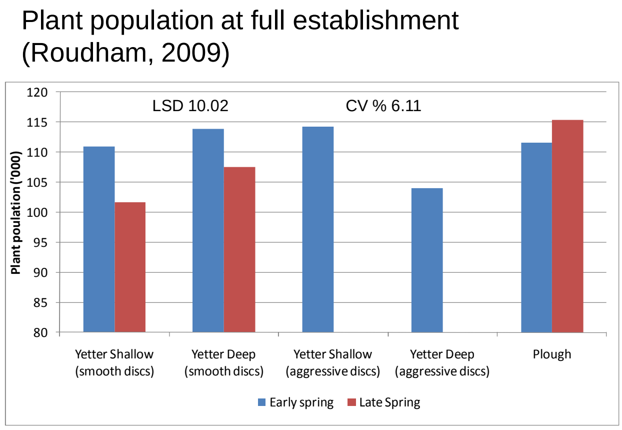
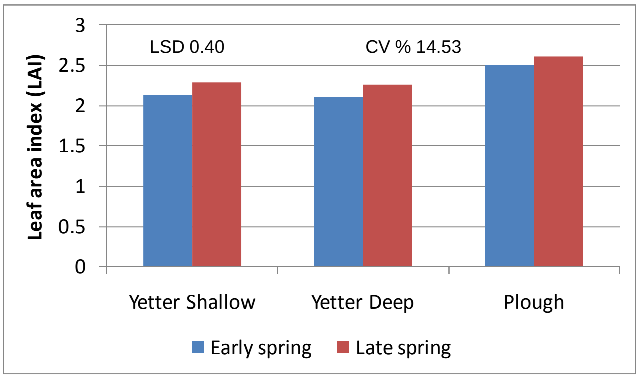


Figure 8: Effect of cultivation on plant population at full establishment (Roudham, 2008 and 2009).

In 2009 final plant populations compared favourably to the plough when using early spring cultivation with the Yetter (using the smooth disc, either shallow or deep, or the aggressive discs at the shallow depth). Both systems achieved plant populations of approximately 111,000 and 112,000 plants/ha (see Figure 8). Late spring cultivation using the Yetter appeared to perform less well than ploughing. Final plant populations in 2009 tended to be slightly higher than the optimum recommended of 80-100,000 plants/ha, although the effect on final yield would not be expected to be substantial due to yields becoming relatively constant above populations of 100,000/ha (BBRO Project 06/05).

Light interception: The size of the canopy was measured at canopy closure (meeting between the rows) using a SunScan light meter. This measures the amount of light penetrating the canopy at ground level and determines the leaf area index of the crop (LAI). Draycott (2006) reported that to achieve 85-90% interception of sunlight the crop required an LAI of 3-4; the crop is required to reach this leaf area by mid July to maximise interception of radiation. During 2008 light intercepted at canopy closure was not significantly different between the Yetter and plough tillage. The late spring cultivation timings in particular resulted in a LAI score of 2.3 and 2.6 respectively. The lower LAI scores resulting from the earlier cultivation timing when using the Yetter are likely to have occurred from a thinner crop that was also indicated by lower plant population counts. LAI in 2009 indicated that the Yetter was significantly lower than the plough; this is surprising given that plant populations between the systems were comparable. The reduction in LAI using the Yetter maybe as a result of a slight delay in emergence compared to plough tillage. Draycott (2006) reported that the more quickly the seedlings emerge, the more rapidly they will grow and thus the leaf area required for efficient light interception is reached more swiftly.

Leaf area index at canopy closure (Roudham, 2008)



Leaf area index at canopy closure (Roudham, 2009)

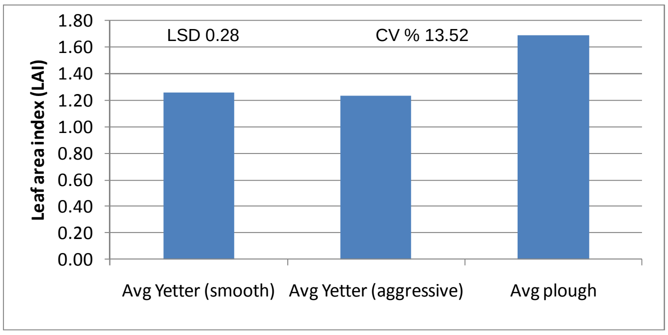


Figure 9: Effect of cultivation on leaf area index at canopy closure (Roudham, 2008 and 2009).

Crop yield and quality

Adjusted yield; The sugar beet crop was harvested in mid November (2008) and early December (2009) by hand; therefore it should be emphasised that losses are reduced due to minimal root damage during the harvesting process. Crop yield in 2008 (see Table 3) indicated that the Yetter was approximately 10t/ha lower than the plough; this is possibly attributed to the lower plant populations that were achieved using strip tillage. Adjusted yield in 2009 when using the Yetter was not significantly different to that of the plough and would indicate that using strip tillage (using either aggressive or smooth discs) and ploughed yields were directly comparable. Cultivation at the late spring timing is common practice on many farms on this soil type due to the risk that cultivating the soil too early increases the risk of the soil slumping; comparing the Yetter with the plough at these timings resulted in yields of 71 and 74 t/ha respectively in 2009. Sugar content was unaffected by cultivation system in either season (see Tables 3 and 4).

System developments (including fitting aggressive discs) to the Yetter for the start of the 2009 season allowed for improved crop establishment and growth that was similar to the plough and whilst the adjusted yields using the Yetter were comparable to ploughing in only one season out of two it must be emphasised that all yields are respectable given that the average commercial yield in sugar beet in England is approximately 60 t/ha (DEFRA June Census 2008).

Table 3: Adjusted crop yield and sugar content (Roudham, 2008).

Adjusted crop yield and sugar content (Roudham, 2008)

	Yield (t/ha)			**Sugar (%)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter	94.6	92.1	**93.4**	18.2	18.0	**18.1**
Late Yetter	92.5	95.4	**94.0**	18.1	18.0	**18.1**
Early Plough	-	106.4	**106.4**	-	18.0	**18.0**
Late plough	-	105.5	**105.5**	-	18.2	**18.2**
LSD (P=.05)	10.75			0.60		
CV %	9.25			2.8		
Sig.	P=<0.05			No sig (0.92)		

Table 4: Adjusted crop yield and sugar content (Roudham, 2009).

Adjusted crop yield and sugar content (Roudham, 2009)

	Yield (t/ha)			**Sugar (%)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter (smooth)	66.2	73.9	**70.1**	18.4	18.3	**18.4**
Early Yetter (aggressive)	74.5	66.6	**70.6**	18.6	18.4	**18.5**
Late Yetter (smooth)	72.5	69.1	**70.8**	18.3	18.3	**18.3**
Early Plough	-	80.7	**80.7**	-	18.4	**18.4**
Late plough	-	74.0	**74.0**	-	18.5	**18.5**
LSD (P=.05)	11.45			0.68		
CV %	2.48			10.59		
Sig.	No sig (p=0.21)			No sig (p=0.96)		

Sugar beet root fanginess and impurities; During harvest all roots were assessed for fanginess to look at the impact of cultivations may have on root growth. An increase in root fanginess can lead to greater harvester losses and therefore decrease the yield of the crop. In both 2008 and 2009 analysis of root fanginess (see Appendix C) indicated no differences between the Yetter and ploughing. This would suggest that the cultivation of a narrow strip using the Yetter provided suitable conditions for tap root development. Results on root impurities (see Appendix C) would suggest that there were few differences between the tillage systems.

Margins
Summary financial analysis from the 2008 and 2009 season is presented in Table 5 with a breakdown of costs presented in Appendix D. The margin analysis is based on output (crop yield multiplied by crop price) minus cultivation costs associated with establishing the sugar beet crop (excluding drilling which would be a standard cost across both systems). All input costs (including fertiliser and herbicides) were omitted because all treatments received a standard farm input approach.

The financial performance using the Yetter in 2008 indicated a lower margin than the plough this was largely as a result of the lower yields associated with the Yetter. In 2009 the margins between the systems were highly comparable, particularly at the late spring cultivation timing which would be typical of this soil type. The interpretation presented here is based on representative financial inputs and needs to be considered in the context of the specific costs used and the speed of operation (land area covered) as well as return per unit area. Specifically, given the Yetter can have faster operating speeds and reduce the number of passes required compared to plough systems it is possible that using the Yetter could increase the timeliness of operations and allow for other farm operations (in the wider farm rotation) to be managed more efficiently.

Table 5: Effect of cultivation system on financial return on a light soil (calculated as gross output minus cultivation costs) presented as £/ha.

Margin – Roudham 2008 and 2009 seasons

	2008 Margin (£/ha)					
	Early spring cultivation			Late spring cultivation		**Mean**
	Shallow	Deep	**Mean**	Shallow	Deep	
Strip till – smooth disc	2241	2182	**2212**	2181	2250	**2216**
Plough	-	2475	**2475**	-	2452	**2452**

	2009 Margin (£/ha)					
	Early spring cultivation		**Mean**	Late spring cultivation		**Mean**
	Shallow	Deep		Shallow	Deep	
Strip till – smooth disc	1691	1880	**1786**	1855	1756	**1806**
Strip till – aggressive disc	1907	1692	**1800**	-	-	**-**
Plough	-	2013	**2013**	-	1836	**1836**

Sugar beet price = £24/t (2008) £26/t (2009) Diesel = 43ppl (2008) 55ppl (2009)
Strip tillage operations = 1x strip tillage Plough operations = 1x plough + 1x power harrow

Strip tillage for medium land sugar beet production

Cultivations

A range of cultivation timings in autumn through spring (early autumn, late autumn, early spring and late spring) were carried out in 2008 in a range of soil moisture conditions (16-26% soil moisture). The autumn established strips tended to slump over winter and form a hard surface cap which were less conducive to drilling with the precision drill 'shoe-type' opener. In 2009 no autumn cultivations occurred because of the difficult weather conditions; all 2009 cultivation timings occurred late February and early April into improved soil conditions (soil moisture content 17.5% and 16.5% respectively). Soil conditions were not always ideally suited to the Yetter and some smearing of the soil occurred particularly when using the smooth discs at the higher soil moisture contents.

Plough cultivations included a secondary cultivation with a power harrow to produce a seedbed followed by drilling whilst strip tillage was followed directly by the drilling operation. All drilling was completed on a single day (either 9th April 2008 or 7th April 2009) to achieve a target plant population of 80,000 to 100,000 plants/ha. Crop emergence followed within 14-21 days of drilling; delayed emergence, particularly in 2009, when a period of dry weather followed drilling resulted in later emergence across all treatments.

Soils physical properties

Soil temperature; During 2008 soil temperature was monitored at 5 cm both within and between rows comparing the Yetter (shallow or deep) and plough at the early spring cultivation timing. As with the light soil type; the data indicated no consistent differences in soil temperature (between early April and late May) in any treatment (data not shown).

Soil penetrometer and shear vane measurements; Measurements in relation to cultivation method are presented in Figures 10 and 11 (within row and between row respectively) for the 2008 season; further results (2009 season) can be found in Appendix B. Differences presented in Figure 10, as measured within row, indicate that generally using the Yetter at the shallow cultivation depth (regardless of cultivation timing) resulted in stronger soils than when using plough tillage. Using the deeper cultivation depth with the Yetter did, to a degree, reduce the strength of the soil down to a depth of approximately 20 cm (maximum cultivation depth of the Yetter) and resulted in resistance levels comparable to the plough. Results shown in Appendix B (2009) indicate that differences in soil strength between tillage systems were similar although there is some suggestion that at depths greater than 18 cm soil strength increased with the Yetter. Using the Yetter was likely to have resulted in smearing by the disc/tine during cultivations when soil moisture content was high.

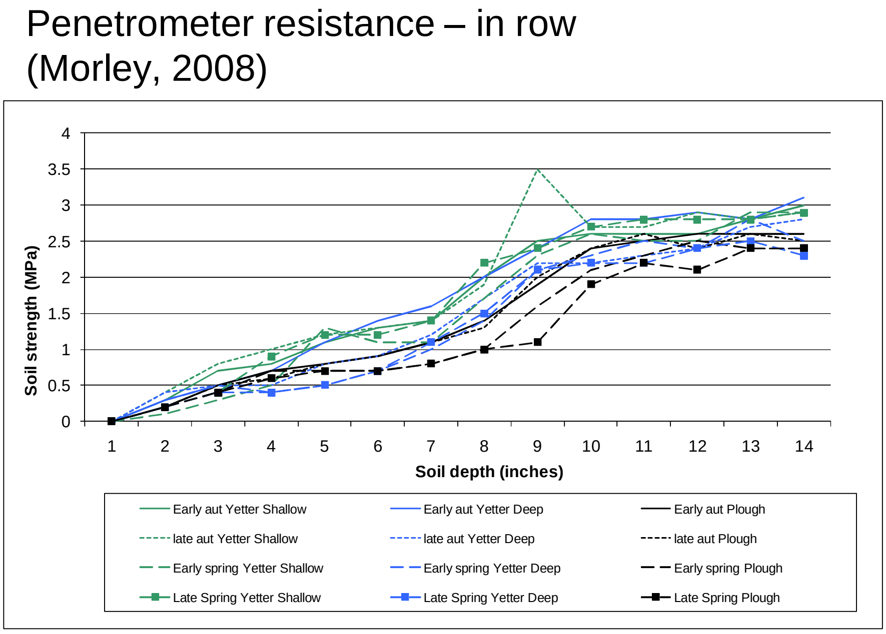


Figure 10: Effect of cultivation on soil penetrometer resistance within rows (Morley, 2008).

Soil penetrometer data between rows (see Figure 11 and Appendix B) is largely similar across seasons whereby the use of the Yetter increased the strength of the soil compared to the plough (this broadly reflects the effect of undisturbed soil areas when using the Yetter).

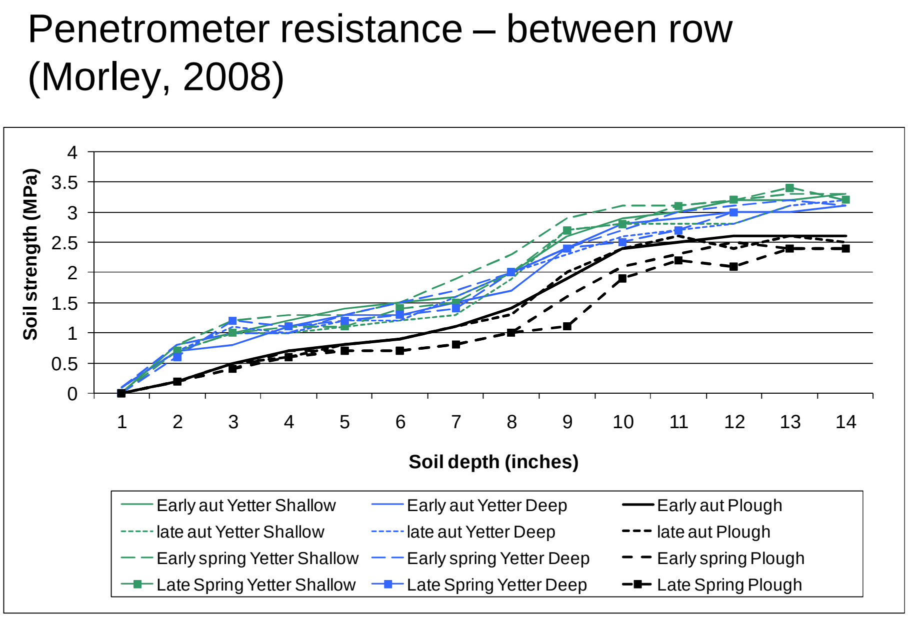
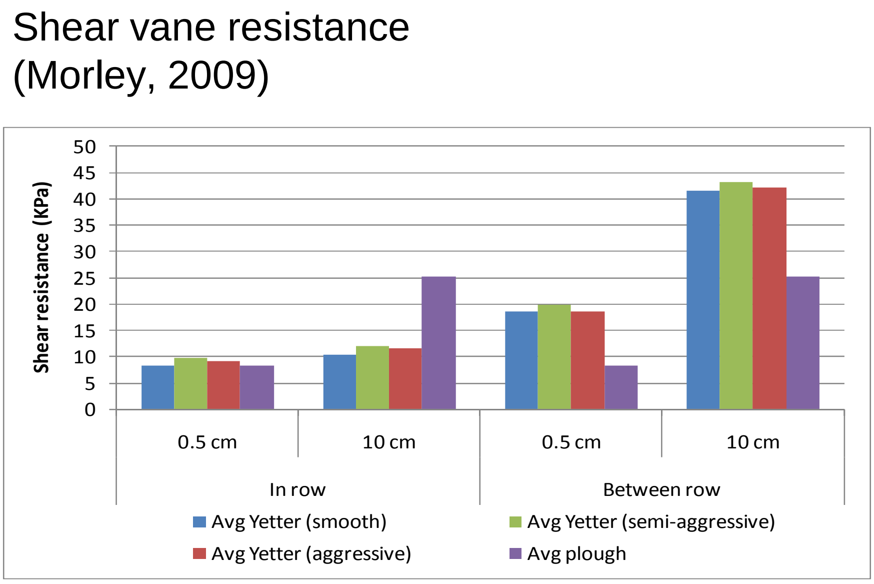


Figure 11: Effect of cultivation on soil penetrometer resistance between rows (Morley, 2008).

The effect of cultivation on soil cohesion using a shear vane meter, both within and between rows, is shown in Figure 12 (2009) and Appendix B (2008). Measurements during 2008 indicated no consistent trend in changes to soil cohesion between tillage treatments and would suggest that consolidation within the row was adequate when using the Yetter. In 2009 surface cohesion (5 cm) indicated similar resistance within row across all cultivation treatments but at 10 cm the Yetter reduced the level of soil cohesion and therefore consolidation. This again may be a result of poorer cultivation conditions resulting in smearing / slotting of the strip. As with results from the light soil type cohesion between rows was generally higher when using the Yetter.



LSD			CV %		
	0-5cm	10 cm		0-5cm	10 cm
Within row	1.8	4.1	Within row	12.3	19.5
Between row	1.8	3.8	Between row	18.7	43.0

Figure 12: Effect of cultivation on soil cohesion within and between rows (Morley, 2009).

Crop establishment

Plant population; Final plant populations achieved using strip tillage were significantly lower than when using the plough in 2008 and 2009 (see Figure 13) on medium soils. The reduced plant population in 2008 indicated that poor establishment had resulted from the autumn cultivated Yetter treatments and this is believed to be an effect of the strips slumping over winter and resulting in poorer conditions at drilling (that led to inconsistent drilling depth and a proportion of seed placement on the surface due to the drill being unable to penetrate the slumped soil). The early spring cultivation timing with the Yetter resulted in the highest plant populations of an average of 66,000 plants/ha; although this is still sub-optimal for maximising yields. In 2009 all Yetter cultivations led to poorer establishment than the plough; probably due to the impact of seedbed consolidation (as indicated by shear vane measurements). In both seasons all plough tillage treatments resulted in a plant population of approximately 100,000/ha.

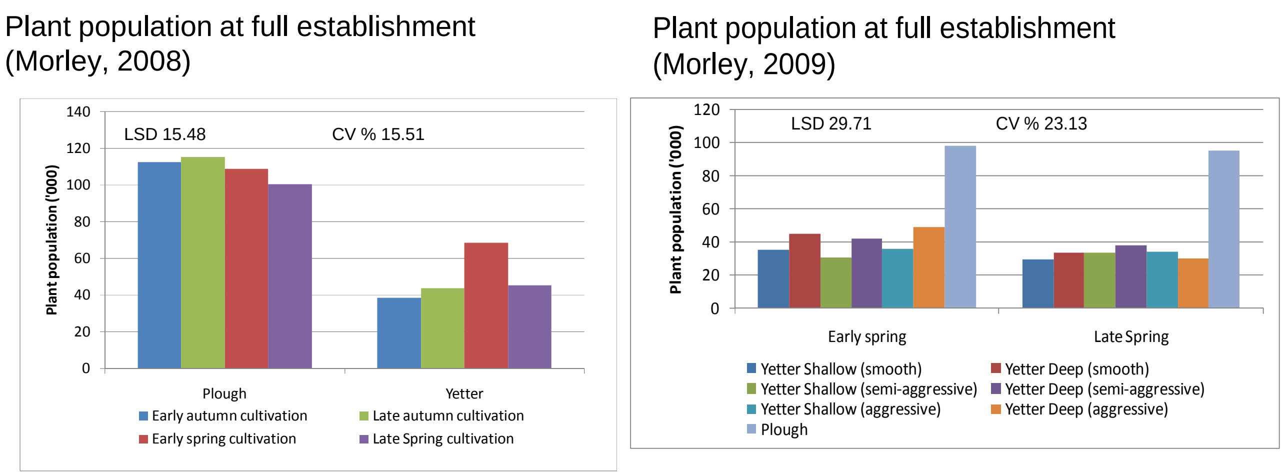
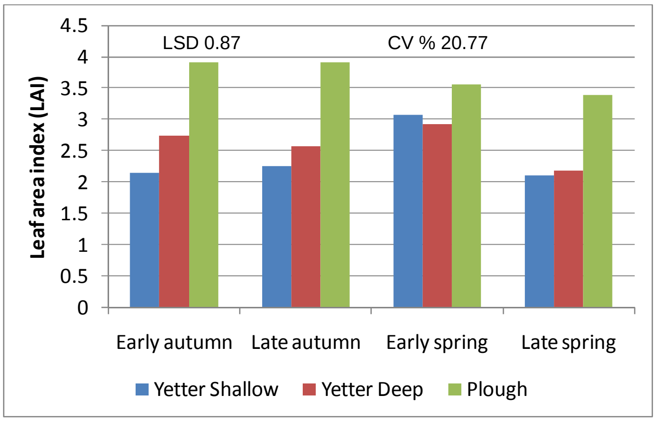


Figure 13: Effect of cultivation on plant population at full establishment (Morley, 2008 and 2009).

Light interception: During 2008 light intercepted at canopy closure was significantly lower in early autumn, late autumn and late spring Yetter treatments compared to the plough. However for the early spring cultivations the Yetter was comparable to the plough (at the analogous cultivation timing); this resulted in an LAI score of 3.0 and 3.5 respectively. The lower LAI scores resulting from the earlier cultivation timings when using the Yetter are likely to have occurred from a thinner crop, this was also reflected in lower plant population counts. The LAI in 2009 indicated that the Yetter was significantly lower than the plough (LAI of 2.0 and 4.0 respectively) in all treatments reflecting the low plant populations that occurred when using the Yetter.

Leaf area index at canopy closure (Morley, 2008)



Leaf area index at canopy closure (Morley, 2009)

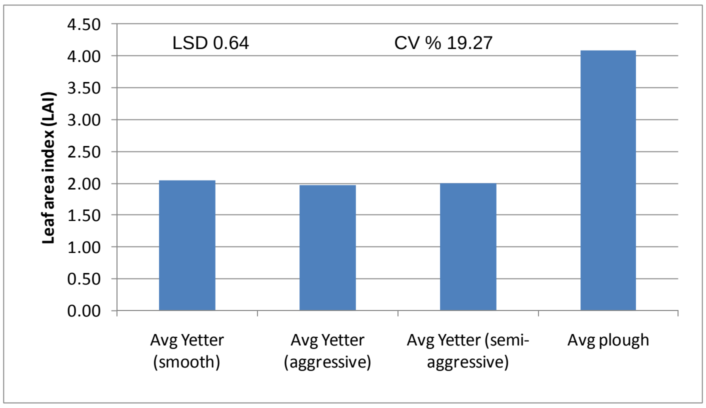


Figure 14: Effect of cultivation on leaf area index at canopy closure (Morley, 2008 and 2009).

Crop yield and quality

Adjusted yield; The sugar beet crop was harvested in mid October (2008) and early December (2009) by hand therefore it should be emphasised that losses are reduced due to minimal root damage during the harvesting process. Harvest data in 2008 (see Table 6) indicated that cultivations during early autumn, late autumn and late spring using the Yetter resulted in significantly lower yields compared to the plough (averaged across cultivation timings at 66 t/ha and 81 t/ha respectively). This can be attributed to the lower plant populations that were achieved under these treatments. Adjusted yield for the Yetter, at the early spring cultivation timing, was 74 t/ha compared to ploughing that resulted in a mean yield of 81 t/ha.

In 2009 (see Table 7) adjusted yield did not differ significantly between the Yetter and the plough, although the variation in yields within and between treatments was particularly high when using the Yetter. The mean adjusted yield using the Yetter with semi-aggressive discs, at the late spring cultivation timing, gave the closest yields to that of the plough (85 t/ha and 90 t/ha respectively). Given that the plant population was sub-optimum in all Yetter treatments it is likely that the plants that established compensated for growth due to reduced intra-specific competition and the resulting hand harvest may have exaggerated these differences compared to commercial lifting processes. As with the light land site sugar content was unaffected by cultivation system in either season (see Tables 6 and 7).

Table 6: Adjusted crop yield and sugar content (Morley, 2008).

Adjusted crop yield and sugar content (Morley, 2008)

	Yield (t/ha)			**Sugar (%)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early autumn Yetter	50.1	65.2	**57.7**	16.9	17.1	**17.0**
Late autumn Yetter	67.0	64.6	**68.8**	17.0	16.4	**16.7**
Early spring Yetter	75.5	73.2	**74.4**	17.4	17.0	**17.2**
Late spring Yetter	67.3	59.2	**63.3**	16.6	16.4	**16.5**
Early autumn plough	-	85.0	**85.0**	-	17.3	**17.3**
Late autumn plough	-	77.5	**77.5**	-	17.0	**17.0**
Early spring plough	-	83.6	**83.6**	-	17.4	**17.4**
Late spring plough	-	79.7	**79.7**	-	16.7	**16.7**
LSD (P=.05)	17.20			0.86		
CV %	16.85			3.5		
Sig.	P=<0.001			No sig (p=0.20)		

Table 7: Adjusted crop yield and sugar content (Morley, 2009).

Adjusted crop yield and sugar content (Morley, 2009)

	Yield (t/ha)			**Sugar (%)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter (smooth)	70.4	74.9	**72.7**	16.7	16.9	**16.8**
Early Yetter (semi-aggressive)	69.4	75.3	**72.4**	16.7	17.0	**16.9**
Early Yetter (aggressive)	77.7	77.6	**77.7**	17.6	17.2	**17.4**
Late Yetter (smooth)	76.5	70.7	**73.6**	16.7	17.1	**16.9**
Late Yetter (semi-aggressive)	89.0	81.6	**85.3**	17.0	16.7	**16.9**
Late Yetter (aggressive)	79.3	59.7	**69.5**	17.2	16.4	**16.8**
Early Plough	-	86.0	**86.0**	-	16.9	**16.9**
Late plough	-	89.6	**89.6**	-	16.8	**16.8**
LSD (P=.05)	21.4			0.69		
CV %	19.26			2.87		
Sig.	No sig (p=0.32)			No sig (p=0.19)		

<u>*Sugar beet root fanginess and impurities*</u>; During harvest all roots were assessed for fanginess to look at the impact that cultivations may have on root growth. In 2008 no significant root fanginess occurred in any treatment. However, in 2009 analysis of root fanginess (see Appendix C) indicated differences between the Yetter and ploughing that would suggest that the cultivation using the Yetter on a heavier soil type had affected root growth to some degree. Results on root impurities (see Appendix C) would suggest that there were some differences between the tillage systems and it would seem likely that the larger crowns associated with the strip tillage treatments would reduce the quality characteristics of the sugar beet. The impact of higher root impurities can reduce extractable sugar (calculated from an equation reported by Carruthers and Oldfield (1962)) although the reduction in extractable sugar between tillage systems tends to be

small (approximately 93.42% for the plough and 92.53% for the Yetter) and unlikely to be significant (data not shown).

Margins

Summary financial analysis from the 2008 and 2009 season is presented in Table 8 with a breakdown of costs presented in Appendix D. The margin analysis is based on output (crop yield multiplied by crop price) minus cultivation costs associated with establishing the sugar beet crop (excluding drilling which would be a standard cost across both systems). All input costs (including fertiliser and herbicides) were omitted because all treatments received a standard farm input approach.

Whilst the financial performance using the Yetter in 2008 resulted in lower margins than the plough this was ostensibly a result of the lower yields associated with the Yetter. In 2009 the margins were generally lower using the Yetter compared to the plough although the late spring cultivation timing using the semi-aggressive discs resulted in comparable margins to the early and late plough. The financial performance is primarily governed by yield and as a result the use of the plough often resulted in the highest yields and therefore the highest margins. However, at particular cultivation timings (mainly the spring timings) the Yetter margins compared favourably to the plough, within +/- £140/ha or approximately 5%; given the variability within the yield data (CV% 16-19) these margins reflect the potential for the Yetter to provide an alternative to ploughing under defined timings and disc configuration.

Table 8: Effect of cultivation system on financial return on a medium soil (calculated as gross output minus cultivation costs) presented as £/ha.

Margin – Morley 2008 and 2009 seasons

	2008 Margin (£/ha)											
	Early autumn cultivation		**Mean**	Late autumn cultivation		**Mean**	Early spring cultivation		**Mean**	Late spring cultivation		**Mean**
	Shallow	Deep		Shallow	Deep		Shallow	Deep		Shallow	Deep	
Strip till – smooth disc	1173	1525	**1349**	1579	1511	**1545**	1783	1719	**1751**	1587	1382	**1485**
Plough	-	1962	**1962**	-	1780	**1780**	-`	1928	**1928**	-	1835	**1835**

	2009 Margin (£/ha)					
	Early spring cultivation			Late spring cultivation		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Strip till – smooth disc	1802	1908	**1855**	1959	1799	**1879**
Strip till – semi-aggressive disc	1775	1919	**1847**	2285	2081	**2183**
Strip till – aggressive disc	1991	1979	**1985**	2033	1511	**1772**
Plough	-	2152	**2152**	-	2244	**2244**

Sugar beet price = £24/t (2008) £26/t (2009)   Diesel = 43ppl (2008) 55ppl (2009)
Strip tillage operations = 1x strip tillage   Plough operations = 1x plough + 1x power harrow

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. A preliminary study to evaluate strip tillage mechanisms for sugar beet (including the Claydon drill and the Yetter Maverick strip tillage implement) was undertaken in autumn 2007. Initial findings from using these machines (in their current unmodified form) identified that the Yetter Maverick created more favourable seedbed conditions for sugar beet establishment, by cultivating defined strips and handling crop residue away from the row.

When looking at the performance of the Yetter for sugar beet production, the system has shown significant potential on light land soil types provided that adequate consolidation can be achieved. The light land site performed well and the Yetter produced adequate plant populations of at least 80,000 plants/ha in both seasons. Implement configuration (disc selection) and / or the timing of cultivation appeared to make little difference on performance suggesting that the Yetter could be well suited to light land sugar beet production, allowing for improved timeliness of operations from fewer field passes for cultivation. As a result the performance of strip tillage (including adjusted yield and margins) indicated that the Yetter was comparable to plough tillage.

On the medium soil the Yetter resulted in inadequate plant populations which were believed to be a result of poor seedbed consolidation and / or seedbed tilth in the majority of situations. Seedbed quality following autumn strip cultivations (where the soil was found to have slumped over winter) caused drilling difficulties when a standard ‘shoe-type’ opener was used that resulted in inconsistent seed depth placement. However, there was an indication that early or late spring cultivation, under suitable moisture conditions resulted in improved performance under strip tillage and was comparable to the plough. On the medium soil type disc configuration appeared to have a lesser effect on improving crop establishment and yield compared to cultivation timing, which appeared to have a significant effect. This would suggest that the Yetter implement was more sensitive to soil moisture conditions at the time of cultivation. Ploughing resulted in the highest margin figures in the majority of situations. When using the Yetter on medium soils it is considered that achieving plant populations similar to that of the plough is fundamental for comparable performance across systems; therefore further work to improve seedbed consolidation and crop establishment would be prudent in developing strip tillage for a wider range of soil types.

Further study

Further studies to improve strip tillage performance on medium soils are considered necessary for developing strip tillage for commercial adoption on a wider range of soil types. It is believed that much of the reduced performance from the Yetter is as a result of poor seedbed consolidation and / or seedbed tilth. There are likely to be a number of possible minor modifications that could be utilised for improving crop establishment. These may include improving consolidation / tilth during cultivation by fitting a press wheel to the rear of the cultivator to firm/level the seedbed ahead of drilling. Other modifications could be targeted to the drilling operation where further study of strips cultivated in the autumn may require a light finger tine mounted ahead of the drill to freshen up the seedbed that would allow improved seed depth placement. Further application of the strip tillage technique could be undertaken on organic ‘fen’ soils whereby the current use of a barley cover crop to reduce the risk of wind blow damaging the emerging sugar beet crop is common place. The use of strip tillage directly into stubble could negate the need for these barley cover crops resulting in a saving in both time and inputs. Much work is also required on quantifying the effects that strip tillage may have on reducing run-off from fields into water courses (of relevance under the Water Framework Directive). Further sugar beet establishment trials (as part of the National Agronomy Centre programme) using strip tillage at TAG Morley have been initiated in spring 2010 and the emerging crop has established well (see photographs in Appendix G).

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Appendix A – Soil nutrient status

Soil mineral and nutrient status - 2008 and 2009

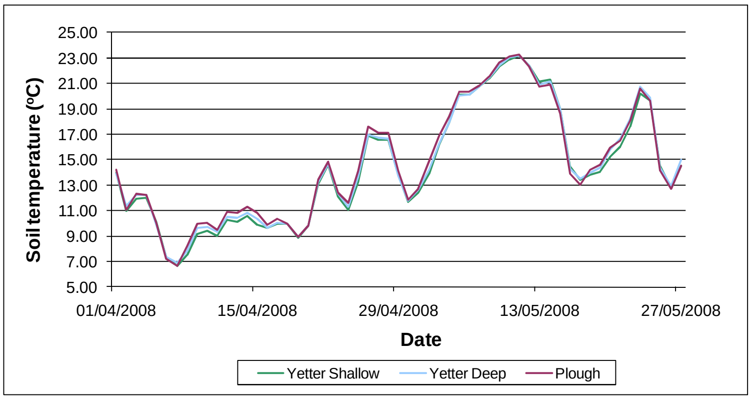
Roudham	**Available phosphorus (mg/l)**	**Available potassium (mg/l)**	**Available magnesium (mg/l)**	**Soil pH**
2008	32.2	117	15	8.0
2009	25.6	81	58	7.9

Morley	**Available phosphorus (mg/l)**	**Available potassium (mg/l)**	**Available magnesium (mg/l)**	**Soil pH**
2008	14.8	164	37	7.2
2009	20.2	96	25	7.7

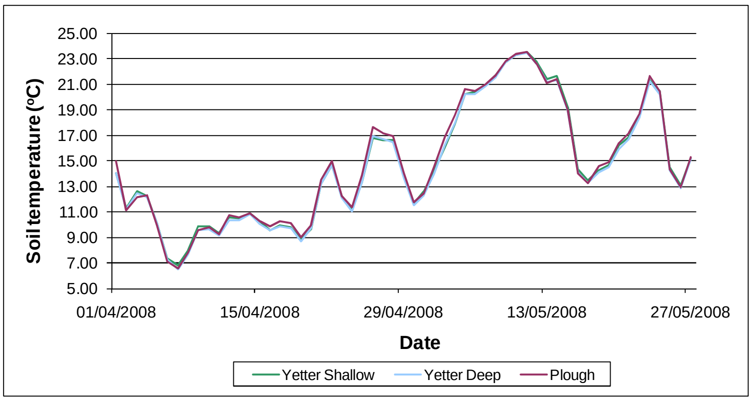
Appendix B – Soil physical properties

Soil temperature data

Soil temperature – within row
(Roudham, 2008)

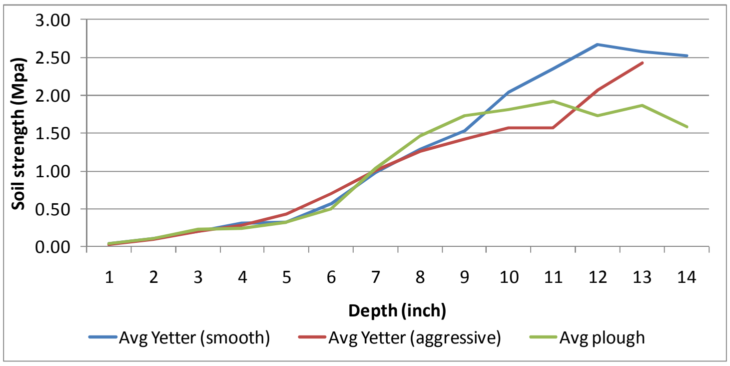


Soil temperature – between row
(Roudham, 2008)

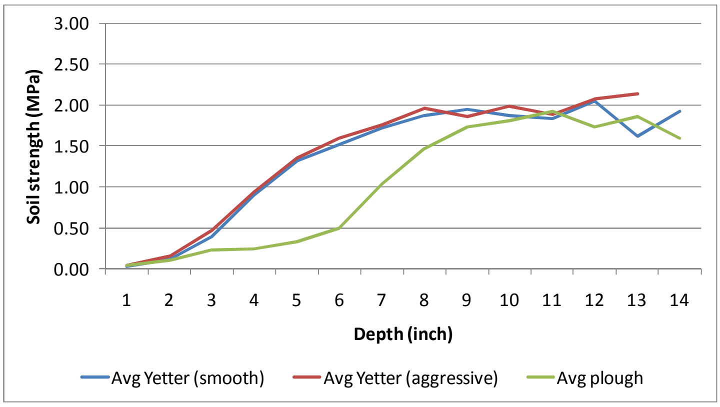


Soil penetrometer resistance

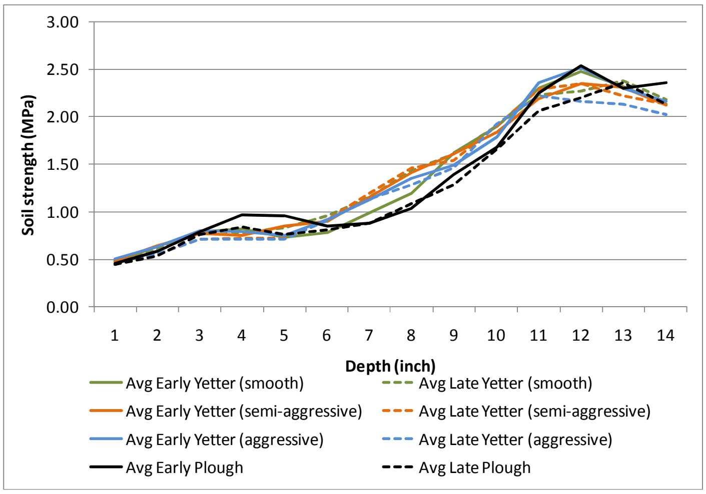
Penetrometer resistance – in row
(Roudham, 2009)



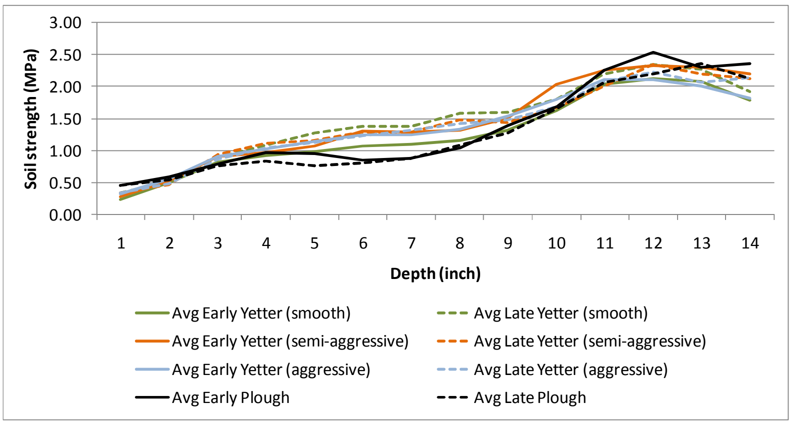
Penetrometer resistance – between row (Roudham, 2009)



Penetrometer resistance – in row (Morley, 2009)

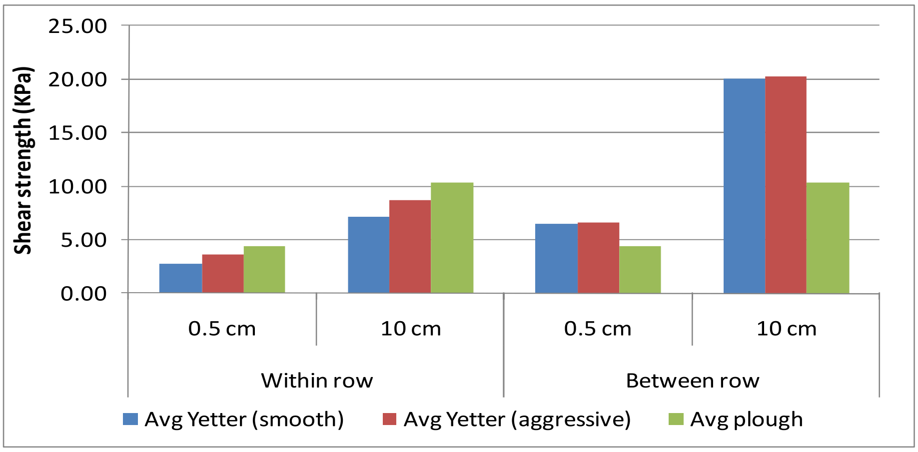


Penetrometer resistance – between row (Morley, 2009)



Shear vane resistance

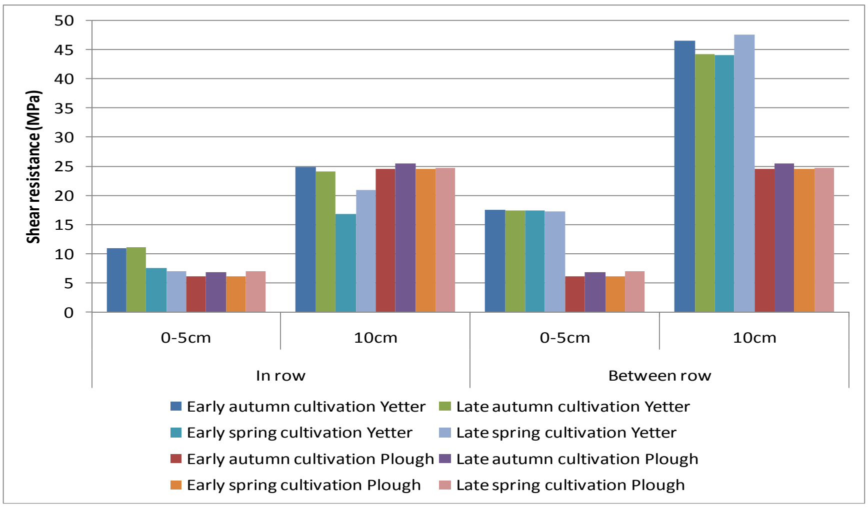
Shear vane resistance
(Roudham, 2009)



LSD	0-5cm	10 cm
Within row	1.3	2.0
Between row	2.4	6.8

CV %	0-5cm	10 cm
Within row	22.8	13.3
Between row	19.9	18.5

Shear vane resistance
(Morley, 2008)



LSD	0-5cm	10 cm
Within row	1.8	7.3
Between row	1.7	6.8

CV %	0-5cm	10 cm
Within row	14.9	22.3
Between row	6.8	10.1

Appendix C –Crop performance

Sugar beet root fanginess and impurities

Sugar beet fangyness (Roudham, 2008)

	Nil (%)			Slight (%)			Moderate (%)		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter	95	94	**95**	4	4	**4**	1	2	**2**
Late Yetter	93	92	**93**	4	5	**5**	3	3	**3**
Early Plough	-	95	**95**	-	3	**3**	-	2	**2**
Late plough	-	94	**94**	-	4	**4**	-	2	**2**
LSD (P=.05)	2.8			2.1			2.1		
CV %	2.5			45.2			91.0		
Sig.	No sig (p=0.39)			No sig (p=0.40)			No sig (p=0.68)		

Sugar beet fangyness (Roudham, 2009)

	Nil (%)			Slight (%)			Moderate (%)		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter (smooth)	93	95	**94**	7	5	**6**	0	0	**0**
Early Yetter (aggressive)	96	95	**96**	4	5	**5**	0	0	**0**
Late Yetter (smooth)	93	95	**94**	7	5	**6**	0	0	**0**
Early Plough	-	96	**96**	-	4	**4**	-	0	**0**
Late plough	-	96	**96**	-	4	**4**	-	0	**0**
LSD (P=.05)	3.5			3.4			1.9		
CV %	2.5			46			204		
Sig.	No sig (p=0.28)			No sig (p=0.27)			No sig (p=0.49)		

Sugar beet impurities (Roudham, 2008)

	K (mg/100g sugar)			Na (mg/100g sugar)			Amino-N (mg/100g sugar)		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter	879	855	**867**	53	54	**54**	40	39	**40**
Late Yetter	827	839	**833**	48	51	**50**	38	38	**38**
Early Plough	-	841	**841**		45	**45**		42	**42**
Late plough	-	823	**823**		40	**40**		40	**40**
LSD (P=.05)	43.4			7.0			3.6		
CV %	4.3			11.9			7.59		
Sig.	No sig (p=0.13)			P=<0.05			No sig (p=0.36)		

Sugar beet impurities (Roudham, 2009)

	K (mg/100g sugar)			Na (mg/100g sugar)			Amino-N (mg/100g sugar)		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter (smooth)	652.6	674.3	**663.5**	31.9	32.0	**32.0**	23.2	23.8	**23.5**
Early Yetter (aggressive)	662.3	686.3	**672.8**	25.8	24.0	**24.9**	24.0	22.5	**23.3**
Late Yetter (smooth)	663.0	684.5	**673.8**	34.0	30.3	**32.2**	31.3	25.0	**28.2**
Early Plough	-	640.2	**640.2**	-	29.0	**29.0**	-	23.5	**23.5**
Late plough	-	651.2	**651.2**	-	22.3	**22.3**	-	23.2	**23.2**
LSD (P=.05)	37.13			13.64			8.98		
CV %	3.73			31.75			24.39		
Sig.	No sig (p=0.16)			No sig (p=0.56)			No sig (p=0.54)		

Sugar beet fangyness (Morley, 2008)

	Nil (%)			**Slight (%)**			**Moderate (%)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early autumn Yetter	96	95	**96**	3	4	**4**	1	0	**1**
Late autumn Yetter	95	93	**94**	4	6	**5**	1	1	**1**
Early spring Yetter	94	94	**94**	4	5	**5**	2	1	**2**
Late spring Yetter	96	95	**96**	3	4	**4**	1	1	**1**
Early autumn plough	-	92	**92**	-	6	**6**	-	2	**2**
Late autumn plough	-	96	**96**	-	3	**3**	-	1	**1**
Early spring plough	-	95	**95**	-	4	**4**	-	2	**2**
Late spring plough	-	96	**96**	-	4	**4**	-	1	**1**
							-		
LSD (P=.05)	5.5			3.7			2.2		
CV %	4.0			65.2			129.5		
Sig.	No sig (p=0.78)			No sig (p=0.75)			No sig (p=0.84)		

Sugar beet fangyness (Morley, 2009)

	Nil (%)			**Slight (%)**			**Moderate (%)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter (smooth)	78.1	78.3	**77.2**	17.6	18.5	**18.1**	4.4	3.2	**3.8**
Early Yetter (semi-aggressive)	77.3	82.7	**80.0**	20.9	14.0	**17.5**	1.8	3.2	**2.1**
Early Yetter (aggressive)	83.6	83.2	**83.4**	15.5	13.9	**14.7**	1.0	2.9	**2.0**
Late Yetter (smooth)	86.7	63.4	**75.1**	11.6	31.0	**21.3**	1.7	5.7	**3.7**
Late Yetter (semi-aggressive)	84.0	82.2	**83.1**	13.6	16.6	**15.1**	2.4	1.2	**1.8**
Late Yetter (aggressive)	75.9	76.7	**76.3**	19.0	16.9	**18.0**	5.1	6.4	**5.8**
Early Plough	-	94.6	**94.6**	-	5.2	**5.2**	-	0.3	**0.3**
Late plough	-	91.1	**91.1**	-	8.0	**8.0**	-	1.2	**1.2**
LSD (P=.05)	13.00			11.34			4.73		
CV %	11.20			50.01			115.83		
Sig.	p=<0.01			p=<0.05			No sig (p=0.22)		

Sugar beet impurities (Morley, 2008)

	K (mg/100g sugar)			**Na (mg/100g sugar)**			**Amino-N (mg/100g sugar)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early autumn Yetter	1009	953	**981**	210	192	**201**	52	52	**52**
Late autumn Yetter	976	994	**985**	214	222	**218**	59	61	**60**
Early spring Yetter	906	903	**905**	157	167	**162**	48	48	**48**
Late spring Yetter	992	940	**966**	220	209	**215**	68	54	**61**
Early autumn plough	-	853	**853**	-	133	**133**	-	46	**46**
Late autumn plough	-	823	**823**	-	127	**127**	-	46	**46**
Early spring plough	-	840	**840**	-	132	**132**	-	49	**49**
Late spring plough	-	840	**840**	-	155	**155**	-	52	**52**
LSD (P=.05)	87.8			53.0			15.1		
CV %	6.5			20.			19.53		
Sig.	p=<0.001			p=<0.001			No sig (p=0.13)		

Sugar beet impurities (Morley, 2009)

	K (mg/100g sugar)			**Na (mg/100g sugar)**			**Amino-N (mg/100g sugar)**		
	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**	Shallow	Deep	**Mean**
Early Yetter (smooth)	934	915	**925**	78.5	70.3	**74.4**	68.3	69.0	**68.7**
Early Yetter (semi-aggressive)	907	866	**887**	72.5	66.0	**69.3**	70.3	62.3	**66.3**
Early Yetter (aggressive)	797	820	**809**	48.5	57.0	**52.8**	53.8	54.0	**53.9**
Late Yetter (smooth)	993	911	**952**	78.8	67.0	**72.9**	74.3	60.8	**67.6**
Late Yetter (semi-aggressive)	929	931	**930**	70.9	76.5	**73.7**	67.0	63.3	**65.2**
Late Yetter (aggressive)	844	1019	**932**	57.0	107.8	**82.4**	55.8	76.0	**65.9**
Early Plough	-	755	**755**	-	51.3	**51.3**	-	56.5	**56.5**
Late plough	-	753	**753**	-	51.0	**51.0**	-	41.5	**41.5**
LSD (P=.05)	144.8			32.6			22.3		
CV %	11.5			33.5			25.1		
Sig.	p=<0.01			No sig (p=0.07)			No sig (p=0.18)		

Appendix D – Cost and margin breakdown

Roudham 2008

	Early spring			Late spring		
	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Plough	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Plough
Area (Ha)	1.00	1.00	1.00	1.00	1.00	1.00
Adjusted yield (t/Ha)	**94.60**	**92.54**	**106.43**	**92.08**	**95.39**	**105.46**
TOTAL YIELD	94.60	92.54	106.43	92.08	95.39	105.46
Price (£/t)	**24**	**24**	**24**	**24**	**24**	**24**
GROSS OUTPUT (£/Ha)	**2270**	**2221**	**2554**	**2210**	**2289**	**2531**
Total	2270	2221	2554	2210	2289	2531
Cultivation Costs (£/ha)						
Plough			55.0			55.0
Power Harrow			24.0			24.0
Deep Sumo						
Shallow Sumo						
Deep Strip tillage		39.0			39.0	
Shallow Strip tillage	29.0			29.0		
Double press						
Cult Drill						
Rolls						
Total Cultivation Costs (£/ha)	**29.0**	**39.0**	**79.0**	**29.0**	**39.0**	**79.0**
GROSS OUTPUT - Cultivation Costs (£/Ha)	**2241.4**	**2182.0**	**2475.3**	**2180.9**	**2250.4**	**2452.0**
(£/Hectare)	2241	2182	2475	2181	2250	2452
(£/Acre)	907	883	1002	883	911	992

Roudham 2009

	Early spring					Late spring		
	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Strip till shallow Aggressive disc	Sugar beet Strip till deep Aggressive disc	Sugar beet Plough	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Plough
Area (Ha)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Adjusted yield (t/Ha)	**66.16**	**73.88**	**74.46**	**66.63**	**80.68**	**72.47**	**69.06**	**73.90**
TOTAL YIELD	66.16	73.88	74.46	66.63	80.68	72.47	69.06	73.90
Price (£/t)	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
GROSS OUTPUT (£/Ha)	**1720**	**1921**	**1936**	**1732**	**2098**	**1884**	**1796**	**1921**
Total	1720	1921	1936	1732	2098	1884	1796	1921
Cultivation Costs (£/ha)								
Plough					59.0			59.0
Power Harrow					26.0			26.0
Deep Sumo								
Shallow Sumo								
Deep Strip tillage		40.0		40.0			40.0	
Shallow Strip tillage	29.0		29.0			29.0		
Double press								
Cult Drill								
Rolls								
Total Cultivation Costs (£/ha)	**29.0**	**40.0**	**29.0**	**40.0**	**85.0**	**29.0**	**40.0**	**85.0**
GROSS OUTPUT - Cultivation Costs (£/Ha)	**1691.2**	**1880.9**	**1907.0**	**1692.4**	**2012.7**	**1855.2**	**1755.6**	**1836.4**
(£/Hectare)	1691	1881	1907	1692	2013	1855	1756	1836
(£/Acre)	684	761	772	685	815	751	710	743

Morley 2008

	Early Autumn			Late Autumn			Early Spring			Late Spring		
	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Plough	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Plough	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Plough	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar Plou
Area (Ha)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.0
Yield (t/Ha)	**50.10**	**65.17**	**85.04**	**67.01**	**64.57**	**77.47**	**75.52**	**73.23**	**83.61**	**67.32**	**59.20**	**79.**
TOTAL YIELD	50.10	65.17	85.04	67.01	64.57	77.47	75.52	73.23	83.61	67.32	59.20	79.
Price (£/t)	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**	**24**
OUTPUT (£/Ha)	**1202**	**1564**	**2041**	**1608**	**1550**	**1859**	**1812**	**1758**	**2007**	**1616**	**1421**	**191**
Total	1202	1564	2041	1608	1550	1859	1812	1758	2007	1616	1421	191
Cultivation Costs (£/ha)												
Plough			55.0			55.0			55.0			55.
Power Harrow			24.0			24.0			24.0			24.
Deep Sumo												
Shallow Sumo												
Deep Strip tillage		39.0			39.0			39.0			39.0	
Shallow Strip tillage	29.0			29.0			29.0			29.0		
Double press												
Cult Drill												
Rolls												
Total Cultivation Costs (£/ha)	**29.0**	**39.0**	**79.0**	**29.0**	**39.0**	**79.0**	**29.0**	**39.0**	**79.0**	**29.0**	**39.0**	**79.**
GROSS OUTPUT - Machinery Costs(£/Ha)	**1173.4**	**1525.1**	**1962.0**	**1579.2**	**1510.7**	**1780.3**	**1783.5**	**1718.5**	**1927.6**	**1586.7**	**1381.8**	**183**
(£/Hectare)	1173	1525	1962	1579	1511	1780	1783	1719	1928	1587	1382	183
(£/Acre)	475	617	794	639	611	720	722	695	780	642	559	74

Morley 2009

	Early Spring									
	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Strip till shallow Semi-aggressive disc	Sugar beet Strip till deep Semi-aggressive disc	Sugar beet Strip till shallow Aggressive disc	Sugar beet Strip till deep Aggressive disc	Sugar beet Plough	Sugar beet Strip till shallow Smooth disc	Sugar beet Strip till deep Smooth disc	Sugar beet Strip till shallo Semi-aggressive
Area (Ha)	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Yield (t/Ha)	**70.41**	**74.92**	**69.37**	**75.33**	**77.71**	**77.64**	**86.02**	**76.47**	**70.73**	**88.99**
TOTAL YIELD	70.41	74.92	69.37	75.33	77.71	77.64	86.02	76.47	70.73	88.99
Price (£/t)	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**26**	**26**
OUTPUT (£/Ha)	**1831**	**1948**	**1804**	**1959**	**2020**	**2019**	**2237**	**1988**	**1839**	**2314**
Total	1831	1948	1804	1959	2020	2019	2237	1988	1839	2314
Cultivation Costs (£/ha)										
Plough							59.0			
Power Harrow							26.0			
Deep Sumo										
Shallow Sumo										
Deep strip tillage		40.0		40.0		40.0			40.0	
Shallow strip tillage	29.0		29.0		29.0			29.0		29.0
Double press										
Cult Drill										
Rolls										
Total Cultivation Costs (£/ha)	**29.0**	**40.0**	**29.0**	**40.0**	**29.0**	**40.0**	**85.0**	**29.0**	**40.0**	**29.0**
GROSS OUTPUT - Cultivation Costs (£/Ha)	**1801.7**	**1907.9**	**1774.6**	**1918.6**	**1991.5**	**1978.6**	**2151.5**	**1959.2**	**1799.0**	**2284.7**
(£/Hectare)	1802	1908	1775	1919	1991	1979	2152	1959	1799	2285
(£/Acre)	729	772	718	776	806	801	871	793	728	925

Appendix E – Field details

Roudham field details 2008

Trial name:	Development of strip tillage techniques in sugar beet production
Crop:	Sugar Beet
Location:	Keepers Piece, Roudham, Norfolk
Trial code:	BV08-002
Soil type:	Freckenham series
Soil analysis (ppm):	P-32.2, K-117, Mg-15, pH-8.0
Previous crop:	Winter Wheat
Drill date:	01/04/08
Seed rate:	Approx 1.18 units/ha
Harvest date:	19/11/08
Variety:	Goya
Drilled plot size:	2m x 24m
Replicates:	X 6

Overall applications to crop

Input type	Product	Product rate	Date
Herbicide:	Betanal Carrera	1.0 l/ha	30/04/08
	Safari Lite	140 g/ha	30/04/08
	Torero	1.0 l/ha	30/04/08
	Fenlander 2	3.0 l/ha	14/05/08
	Goltix 90	0.7 kg/ha	14/05/08
	Lontrel 200	0.35 l/ha	14/05/08
	Raptor	0.7 l/ha	20/05/08
Fungicides:	Domark	0.5 l/ha	28/07/08
	Harveson	0.35 l/ha	28/07/08
	Spyrale	0.75 l/ha	15/09/08
Fertiliser:	Boron	1.0 kg/ha	13/02/08
	N26	180 l/ha	14/04/08
	AN	127 kg/ha	19/05/08
	Headland Stem – nitrate micronutrient	1.0 l/ha	30/04/08
	Headland Stem – nitrate micronutrient	1.5 l/ha	20/05/08
	Yeald Plus - Liquid nutrient	1.8 l/ha	20/05/08
	Headland Stem – nitrate micronutrient	2.5 l/ha	13/06/08
	Headland Mag Sulph – micronutrient	2.5 l/ha	13/06/08
	Headland Stem – nitrate micronutrient	2.5 l/ha	28/07/08
	Headland Stem – nitrate micronutrient	2.5 l/ha	28/07/08
Insecticides:	Vydate	30g / 100m row	01/04/08
Adjuvants:	Silwet	0.05 l/ha	20/05/08

Individual applications to crop

Input type	Planned timing	Actual timing	Date
Cultivations			
Early spring	Early Feb	Early Feb	07/02/08
Late spring	March	April	01/04/08

Other key dates

Assessments	Planned timing	Actual timing	Date
Penetrometer readings			17/04/08
Shear vane meter			23/04/08
Crop vigour		GS 10	23/04/08
Crop establishment at full plant stand		GS 14-16	15/05/08
Crop population at full plant stand		GS 14-16	15/05/08
Plant tissue analysis at full establishment			11/05/08
Soil temperature			01/04/08-27/05/08
Crop GAI score		GS 31-32	04/06/08
Light interception		GS 39	10/07/08
Plant tissue analysis at harvest			17/11/08
Harvest and root fanginess assessment			19/11/08
Crop impurities			25/11/09

Roudham field details 2009

Trial name:	Development of strip tillage techniques in sugar beet production
Crop:	Sugar Beet
Location:	Field 12, Roudham, Norfolk
Trial code:	BV09-002
Soil type:	Freckenham series
Soil analysis (ppm):	P-25.6, K-96, Mg-25, pH-8.0
Previous crop:	Winter Wheat
Drill date:	07/04/09
Seed rate:	Approx 1.33 units/ha
Harvest date:	07/12/09
Variety:	Bobcat
Drilled plot size:	2m x 24m
Replicates:	X 4

Overall applications to crop

Input type	**Product**	**Product rate**	**Date**
Herbicide:	Takron	1.5 l/ha	06/04/09
	Goltix 90	0.75	06/04/09
	Betanal Maxxim	0.5 l/ha	24/04/09
	Torero	1.0 l/ha	24/04/09
	Safari Lite	140 g/ha	24/04/09
	Betanal Expert	1.0 l/ha	20/05/09
	Debut	30 g/ha	20/05/09
	Lontrel 200	0.3 l/ha	20/05/09
Fungicides:	Harveson	0.5 l/ha	13/07/09
	Domark	0.5 l/ha	13/07/09
	Priori Xtra	0.75 l/ha	07/09/09
Fertiliser:	Boron	1.0 kg/ha	19/02/09
	AN	145 kg/ha	06/04/09
	Headland Stem – nitrate micronutrient	1.0 l/ha	24/04/09
	Yeald Plus - Liquid nutrient	1.8 l/ha	20/05/09
	Headland Stem – nitrate micronutrient	2.5 l/ha	03/06/09
	Headland Super 80 – nitrate micronutrient	2.5 l/ha	03/06/09
	Headland Stem – nitrate micronutrient	2.5 l/ha	13/07/09
	Headland Super 80 – nitrate micronutrient	2.5 l/ha	13/07/09
	Headland Stem – nitrate micronutrient	2.5 l/ha	07/09/09
	Headland Super 80 – nitrate micronutrient	2.5 l/ha	07/09/09
Insecticides:	Vydate	30g / 100m row	07/04/09
Adjuvants:	Slither	0.05 l/ha	13/07/09

Individual applications to crop

Input type	**Planned timing**	**Actual timing**	**Date**
Cultivations			
Early spring	Early Feb	Mid Feb	17/02/09
Late spring	March	April	05/04/09

Other key dates

Assessments	**Planned timing**	**Actual timing**	**Date**
Crop establishment at 100% plant stand		GS 11	29/04/09
Crop population at 100% plant stand		GS 11	29/04/09
Crop establishment at full plant stand		GS 14-16	20/05/09
Crop population at full plant stand		GS 14-16	20/05/09
Crop GAI score at full establishment		GS 15-16	22/05/09
Shear vane meter		GS 15-16	22/05/09
Penetrometer readings		GS 15-16	22/05/09
Light interception		GS 39	08/07/09
Crop GAI score at harvest		GS 45	07/12/09
Harvest and root fanginess assessment		GS 45	07/12/09
Crop impurities		GS 45	03/02/10

Morley field details 2008

Trial name:	Development of strip tillage techniques in sugar beet production
Crop:	Sugar Beet
Location:	Sixteen Acres, Morley, Norfolk
Trial code:	BV08-001
Soil type:	Burlingham series
Soil analysis (ppm):	P-14.8, K-164, Mg-37, pH-7.2
Previous crop:	Winter wheat
Drill date:	09/04/08
Seed rate:	Approx 1.18 units/ha
Harvest date:	16/10/08
Variety:	Goya
Drilled plot size:	2m x 24m
Replicates:	X 4

Overall applications to crop

Input type	Product	Product rate	Date
Herbicide:	Clinic	3.0 l/ha	05/10/07
	Better Flowable	2.5 l/ha	11/04/08
	Alpha Phenmedipham 320 SC	0.5 l/ha	09/05/08
	Ethosat 500	0.2 l/ha	09/05/08
	Goldbeet	0.5 kg/ha	09/05/08
	Alpha Phenmedipham 320 SC	0.4 l/ha	22/05/08
	Ethosat 500	0.2 l/ha	22/05/08
	Goldbeet	0.2 kg/ha	22/05/08
	Venzar Flowable	0.1 l/ha	22/05/08
	Debut	10 g/ha	22/05/08
	Twin	1.0 l/ha	09/06/08
	Fusilade Max	0.9 l/ha	09/06/08
Fungicides:	Sanction 25	0.5 l/ha	06/08/08
	Centaur	0.15 l/ha	06/08/08
	Spyrale	0.75 l/ha	06/08/08
Fertiliser:	Blend B 07/08	972 kg/ha	17/09/07
	N27 + S	230 l/ha	11/04/08
	N27 + S	120 l/ha	02/06/08
Adjuvants:	Cropspray 11E	0.5 l/ha	09/05/08
	Cropspray 11E	0.5 l/ha	22/05/08
	Cropspray 11E	0.5 l/ha	09/06/08

Individual applications to crop

Input type	Planned timing	Actual timing	Date
Cultivations			
Early autumn	Late Sept-early Oct	Early Sept	03/09/07
Late autumn	Mid Nov	Mid Nov	16/11/07
Early spring	Early Feb	Mid Feb	11/02/08
Late spring	March	April	09/04/08

Other key dates

Assessments	Planned timing	Actual timing	Date
Shear vane meter		GS 09	30/04/08
Penetrometer readings		GS 09	01/05/08
Crop vigour score		GS 12	13/05/08
Crop establishment at full plant stand		GS 12-14	23/05/08
Crop population at full plant stand		GS 12-14	23/05/08
Plant tissue analysis at full establishment			11/05/08
Soil temperature			09/04/08-09/06/08
Crop GAI score		GS 36-37	24/06/08
Light interception		GS 39	12/07/08
Plant tissue analysis at harvest			11/05/08
Harvest and root fanginess assessment			16/10/08
Crop impurities			25/11/09

Morley field details 2009

Trial name:	Development of strip tillage techniques in sugar beet production
Crop:	Sugar Beet
Location:	Bullswood, Morley, Norfolk
Trial code:	BV09-001
Soil type:	Burlingham series
Soil analysis (ppm):	P-20.2, K-96, Mg-25, pH-7.7
Previous crop:	Winter Wheat
Drill date:	07/04/09
Seed rate:	Approx 1.33 units/ha
Harvest date:	02/12/09
Variety:	Bobcat
Drilled plot size:	2m x 24m
Replicates:	X 4

Overall applications to crop

Input type	**Product**	**Product rate**	**Date**
Herbicide:	Roundup Energy	3.0 l/ha	21/02/09
	Dancer Flow	1.0 l/ha	21/04/09
	Ethosat 500	0.25 l/ha	21/04/09
	MM 70	0.7 l/ha	21/04/09
	Alpha Phenmedipham 320 SC	0.75 l/ha	10/05/09
	Debut	10 g/ha	10/05/09
	Ethosat 500	0.3 l/ha	10/05/09
	Goltix WG	0.2 kg/ha	10/05/09
	Venzar Flowable	0.35 l/ha	10/05/09
	Alpha Phenmedipham 320 SC	0.75 l/ha	20/05/09
	Ethosat 500	0.25 l/ha	20/05/09
	Venzar Flowable	0.2 l/ha	20/05/09
	Debut	10 g/ha	20/05/09
Fungicides:	Sanction 25	0.5 l/ha	31/07/09
	Centaur	0.15 l/ha	31/07/09
	Spyrale	0.75 l/ha	05/09/09
Fertiliser:	SB Blend C	650 kg/ha	29/09/08
	Screed chalk	4.2 kg/ha	01/10/08
	AN	60 kg/ha	17/04/09
	AN	60 kg/ha	17/04/09
Adjuvants:	Cropspray 11E	0.5 l/ha	21/04/09
	Cropspray 11E	0.5 l/ha	10/05/09
	Cropspray 11E	0.5 l/ha	20/05/09

Individual applications to crop

Input type **Cultivations**	**Planned timing**	**Actual timing**	**Date**
Mid – late autumn	Late October – early November	Not achieved due to wet conditions	N/A
Early spring	Feb	Feb	20/02/09
Late spring	March	April	05/04/09

Other key dates

Assessments	**Planned timing**	**Actual timing**	**Date**
Seedbed quality			21/04/09
Crop establishment at 50% plant stand		GS 10	21/04/09
Crop population at 50% plant stand		GS 10	21/04/09
Crop establishment at 75% plant stand		GS 11	29/04/09
Crop population at 75% plant stand		GS 11	29/04/09
Penetrometer readings		GS 14-15	21/05/09
Crop establishment at full plant stand		GS 13-18	28/05/09
Crop population at full plant stand		GS 13-18	28/05/09
Crop GAI score at full establishment		GS 13-18	28/05/09
Shear vane meter		GS 13-18	29/05/09
Light interception		GS 39	08/07/09
Crop GAI score at harvest		GS 49	02/12/09
Harvest and roof fanginess assessment		GS 49	02/12/09
Crop impurities		GS 49	04/02/10

Appendix F – Sugar beet establishment

Sugar beet establishment at TAG Morley, 2010

Sugar beet established using strip tillage, May 2010.

Sugar beet established using plough tillage, May 2010.