The Implementation of Zero Till in the UK: Comparison of Literature to Farm Case Studies

Tom Storr
Dr Paul Wilson

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Abstract

Zero till (ZT) is well established in other parts of the world, particularly The Americas and Australia, however uptake remains relatively small in the UK with only 2.5% of arable area practicing ZT. ZT by definition leaves at least 70% of the soil surface undisturbed and covered in the residues of the previous crop. ZT is practiced on a wide variety of soil types from 90% sand content to 80% clay in climates with up to 2500 mm of rainfall and as low as 250mm. The economic and environmental benefits are widely reported as well as some of the potential problems of ZT such as yield loss, slug and weed control. This paper, through a series of case studies conducted with farmers who implement ZT aims to compare the published literature to their personal findings with the objective of understanding ZT from a practical and theoretical perspective. This paper considers: crop establishment and residues; economics; cover crops; pests, weeds and disease; soil and the environment and conversion to ZT.

ZT farmers have a wide and diverse cropping rotation which is flexible and established according to conditions rather than being fixed and includes a substantial amount of spring crops. In agreement with previous studies, ZT farmers found that establishment cost and time decreased allowing a greater timeliness of operations. The opinion of ZT farmers on the benefits of cover crops is divided, with much discussion and debate on the online forum surrounding the best varieties for use in the UK and the economics of cover crops. ZT farmers have noticed improvements to soil structure as a result of increased worm activity and roots which aid in drainage, carry capacity and help prevent erosion. The two main contradictions to the published literature is that ZT farmers in the UK have not noticed a decrease in yield and that ZT does not exacerbate the problem of blackgrass but rather reduces the incidence of blackgrass. ZT farmers made an informed decision to convert to ZT after much research and have implemented successful systems that work for their farming strategy.

Introduction

Zero till (ZT) is a method of crop establishment that leaves atleast 70% of the soil surface undisturbed with crop residue from the previous crop on the surface. This method of establishment is reported to improve the soil in a number of ways and allows the soil biology to proliferate and perform the job of tillage; the distribution of nutrients and breakdown of crop residues is perform by the soil fauna. Enhancing the soil environment through decreased soil movement reduces the requirement of fuel, horsepower and labour. Through careful management, ZT aims to produce crops of comparable yield and quality to conventional tillage with greater economic efficiency and sustainability to the benefit of the environment. The introduction provides an overview of the research related to ZT.

Crop establishment and residues

Crop establishment under ZT requires careful management of the residues left behind from harvest as the amount of straw yield can be equal to grain yield of cereals (Ehlers & Claupein, 1994), which can create a number of problems. The crop-drilling operation can be severely affected by the amount and form of the residues, height of cut of the previous crop and whether the stubble is still standing, these factors can decrease evaporation of water and incident radiation on the soil surface *(*Mikkola *et al*., 2005). Wet soils can delay drilling by several weeks and may result in fungal phytotoxicity when decomposing straw is in close contact with the seed and is especially a problem with disc drills (Soane *et al.,* 2012). Water soluble toxins, phenolic acids and acetic acid are produced under anaerobic conditions during residue decomposition (Alam, 1990) reducing tillers and yield (Elliott *et al.,* 1976). The phytotoxic effect is more prevalent when the residue is placed below the seed than when placed above although this will result in a delayed emergence (Wuest *et al.,* 2000). Standing residues are more efficient at retaining heat from the bare soil and are better able to absorb radiation than flat residues resulting in soil temperatures warming up 5- 9 days earlier (Flerchinger *et al.,* 2003). Residue management can affect yields; when compared to mouldboard ploughing, ZT yields of oilseed rape (OSR) following spring barley are 2 % higher if straw is removed and 4% lower if straw remains on the surface (Cedell, 1988). Research over 16 years suggests that on clay soils ZT yields decrease by 16% with straw present yet if straw is removed then yields are comparable to mouldboard ploughing (Rydberg, 2010).

Cover crops

Cover crops can benefit the soil, the environment and enhance the system of ZT. A recent study Ramirez-Garcia *et al,* (2015) distinguishes cover crops from catch crops and green manures by their specific properties. The primary role of cover crops is to reduce soil erosion from wind and water with some countries using cover crops to increase water storage and sowing opportunity (Clark *et al.,* 1997). Catch crops aim to absorb a specific compound in the soil to minimise the pollution effect and green manures act as a nutrient source, and are often legumes due to their ability to fix nitrogen. Cover crops can aid weed suppression by outcompeting weeds for resources and by drawing out moisture from the soil. This produces a less favourable environment for blackgrass and allows a more optimum time to establish spring crops when compared to an over-wintered stubble (The Farmers Weekly, 2015). Cover crops also increase diversity in the rotation and create habitats for beneficial insects (Grubinger, 2015). Cover crops are grouped in a number of ways. Firstly, as i) cool or ii) warm season crops, relating to the soil temperature when most rapid growth is required; out of season crops may die back (Grubinger, 2015). Cover crops are then classified according to structure either broadleaved or grasses and whether or not they are a legume. Grasses establish quicker than legumes and tend to be grown for weed suppression rather than when nitrogen contribution to soil is a priority. This rapid growth produces a surplus of biomass which can contribute to the soil organic matter. A NIABTAG trial found that a mixed species cover crop improves yield when compared to single species of cover crop by 9% and 2% respectively. The study concluded that cover crops are only likely to cover the cost of their seed and establishment (Stobart, 2012).

Economics

ZT has a number of economic advantages, mainly lowering the costs associated with establishment; fuel, labour and wearing parts. Machinery and fuel are the most important cost for larger producers (Derpsch *et al.,* 2010) with up to a 70% saving in energy and fuel costs with ZT as well as machinery investment reduced by 50% (Friedrick & Kassam, 2014). Other important economic considerations are cost per hectare (Ha) and time required per Ha to establish a crop, all of which are substantially lower for ZT (table 1). This offers greater efficiency and flexibility for weather dependent operations.

Table 1: Economics of establishment systems in the UK. (Bailey, Unpublished)

Establishment system	Cost per Ha (£/Ha)	Total time (min/Ha)	Typical fuel consumption (l/Ha)
Plough based	70-105	65-150	30-50
Deep non-inversion (12-25 cm)	55- 70	45-70	38-54
Shallow non-inversion tillage (5-10cm)	55-60	24-59	26-28
Zero till	20-30	20-30	8-10

There is much debate surrounding crop yields under ZT with some reports of both increased and decreased yields. Recent research (Pittelkow *et al.,* 2015) shows that across 48 different crops in 63 countries that there is an overall decrease in crop yields under ZT. However Pittelkow *et al*, (2015) show that the response is variable and under certain conditions yields under ZT can be better than conventional tillage. If ZT is implemented alongside the principles of crop rotation and residue retention then yield loss is 2.5% however without these two principles then yield loss is 9.9% compared to conventional tillage. As the time from conversion to ZT increases there is a decrease in yield loss from 3% to nearly 0% if ZT is implemented alongside residue retention and crop rotation; yield losses after 10 years are much greater if neither of the principles are applied. Research in Switzerland lasting over 10 years with different rotations reports that yields are the same if not increased under ZT, yet in Turkey one of the reasons for farmers to abandon ZT was due to lower yields (Derpsch *et al.,* 2010). A study in England with well-drained soil under ZT showed that wheat yielded 105% of that of ploughed soil (Cannell *et al.,* 1986). It is accepted that ZT yields are within 5% of ploughed soils with soil type, weather and crop type influencing factors (Soane *et al.,* 2012) and that within the first 3 years yields are lower than after ploughing (Anken *et al.,* 2006) but improve to 98% of the mean yield for years 18 to 23 (Christian & Ball, 1994) following conversion as soil structure improves.

<u>Weeds, disease and pests</u>

Weed pressure is heavily influenced by the type of tillage, due to weed seed dormancy and germination characteristics. ZT favours perennial grass weeds (Soane *et al.,* 2012) and some annual grass weeds, particularly sterile brome and blackgrass (Basch *et al.,* 2015) whilst dicotyledon weed incidence is similar to after ploughing. Germination and seedling growth of weed seeds can be inhibited by crop residue due to shading, or a reduction in the soil surface temperature (Morris *et al.,* 2010). A study reports that over 7 years fewer weed seeds germinate under un-disturbed soil conditions compared to shallow and deep cultivation (table 2); moss and lichen on undisturbed soils may also prevent weed seed germination (Popay *et al.,* 1994).

Table 2: Effect of cultivation on weed seedling emergence. (Popay, et al., 1994)

Tillage technique	Weed emergence / m^2
Undisturbed	4000
Shallow cultivation	11000
Deep cultivation	28000

Crop residue has the potential to carry over disease from one season to the next, with ‘no till fields particularly vulnerable as ploughing kills the pathogens’ (Perszewski, 2015) however Jordan *et al,* (1997) reached a different conclusion that tillage practices have a limited effect on crop diseases. Some crop diseases appear to be suppressed by the concentration of organic matter near the surface (Ehlers & Claupein, 1994) with most studies showing a decline in incidence of different diseases, however Fortune *et al,* (2003) report that levels of leaf net blotch and rhynchosporium increase under ZT. Under ZT eyespot infestation of winter wheat declines after eight years (Brautigam & Tebrugge, 1997), snow rot of winter cereals was less prevalent in Scotland (Ball & Davies, 1997), take-all decreases, and the incidence of club root in brassicas reduces (Ekeberg & Riley, 1997). Barley Yellow Dwarf Virus decreases as the number of beneficial polyphagous predators in ZT soils is greater and secondly aphids may not be able to recognise young crop plants amongst residues (Jordan *et al.,* 1997).

Pests, mainly slugs which damage wheat seedlings are a concern with ZT due to the increased amount of surface residue. However the undisturbed soils of ZT provide a habitat for carabid beetles which are natural predators of slugs and aphids; the carabid population increases from 0.38/m^2 in a plough based system to 17.6 / m^2 on ZT soils (Kromp, 1999).

Soils and the environment

ZT management of soil induces substantial changes with physical, chemical and biological properties mainly enhanced. There is an increased aggregate stability, bulk density and soil strength due to macropores (30-300 ųm) that are vertical through the soil profile due to worm activity and roots which leads to greater aeration, moisture retention and bearing capacity (Vogeler *et al.,* 2009). These stronger soils of ZT can reduce the risk of lodging (Berry, Personal Communication) however the structural changes can take three to five years to develop. Infiltration rates of ZT soils have been shown to increase compared to ploughed soils, reducing run off as the soil surface is protected from rain droplet impact and there is continuity of vertical macropores between the surface and sub-layers (Ehlers, 1997). There may be an increased acidity near the soil surface of ZT soils due to residue breakdown and nitrification of fertilizers which may decrease the availability of N, P and K for crops. (Ekeberg & Riley, 1997).

Soil organic matter (SOM) increases in ZT soils as the lower temperature reduces oxidation (Sprague & Triplett, 1986) and the rate of nitrogen mineralisation (Blevins & Frye, 1993), however SOM improves structural stability and porosity allowing better root growth (Boatman *et al.*, 1999). There is an increase in biological activity of ZT soils including both microbial mycorrhiza colonization (Brito *et al.*, 2006) and macro fauna such as earthworms, where the population can be up to six times higher than ploughed soils (Fawcett & Towery, 2002). Crop residues, over wintered stubbles and cover crops provide a protective habitat for insects which attract farmland birds and mammals (Fawcett & Towery, 2002).

Barriers to entry and potential problems

Derpsch and Friedrich (2009) report that the main reasons for lack of uptake of ZT continue to be the mind set and tradition of farmers, and the lack of knowledge of how to successfully implement ZT. There is a lack of adequate machinery and herbicides available that suit the needs of ZT practices. In the UK herbicide resistance is developing in weeds such as blackgrass, wild oats and Italian Ryegrass (Davies & Finney, 2002) whilst in America resistance to glyphosate is a concern (Triplett & Dick, 2008). Agricultural policies hinder the uptake of ZT as European subsidies do not incentivise farmers to find sustainable and economical means of producing food efficiently.

The literature mainly refers to research that has been conducted on a small scale, and sometimes focusing on one aspect of ZT with little literature regarding large farm based studies with a focus on the UK. The aim of this study is to report the impact of ZT on a whole farm level, across farms in the UK. The study will capture individual farmer’s knowledge and attitudes towards ZT as well as their practical implementation of ZT.

Materials and Methods

Case studies were used to gain information from participants who practice ZT farming methods as they allow a greater depth of questioning and understanding compared to questionnaires (Merriam, 2009). Case studies enable a broad range of questions to be asked which adequately cover the wide range of aspects of the ZT system with participants providing extra information and explanations. However a questionnaire would allow a greater number of participants to be involved but the information and opinions given would not be as valuable.

The case study questions were based around five topic areas: farm information; crop establishment; pests, weeds & disease; economics; soil and the environment and conversion to ZT. These broad topics were chosen as the main areas of interest following a preliminary literature review discussing the potential benefits and disadvantages of ZT. The questions in the case study were peer reviewed by an Agronomist, a farmer and the research supervisor.

Participants were sourced through the online forum, The Farming Forum (TFF) and through contacts made as the case studies were conducted. Five case studies were completed by farm visits that included a field walk, two participants filled in and returned the case study questions and two case studies were completed by phone interview. Table 3 shows the basic information of the case study farms.

Table 3: Case study farm information.

Case study	Location	Soil Type	Annual rainfall / mm	Arable area / Ha	Farm type	Year of conversion
1	Somerset	Brash/loam & heavy clay	700	200	Mixed	1998
2	Lincolnshire	Peat fen to 90% clay	750	1250	Combinable crops	2002
3	Staffordshire	Light, sandy, medium soil	650	1050	Combinable crops	2010
4	Worcestershire	Silty clay loam	700	250	Combinable crops + grass	1996
5	Kent	Light sand, alluvial & clay	700	350	Combinable crops	2010
6	Kent	Heavy clay	700	400	Combinable crops + grass	1999
7	Essex	Heavy clay	460	145	Combinable crops	2006
8	Leicestershire	Limestone, silty soils	600-700	310	Combinable crops	2001
9	Hertfordshire	Chalky boulder clay	435-720	1011	Combinable crops + cattle	2010

Case study information was collated and compared to literature and the other case studies to find recurring methods or responses. Case study comparisons enable consideration to be given to practicalities not addressed or misrepresented in the scientific literature read.

Forum analysis categorised posts according to content and particular themes from TFF in the Direct Drilling section under the two threads General Discussion and Crops & Agronomy. The forum analysis was conducted on January 22nd 2015 and included 665 observations which were posted between January 2013 and January 2015. The main themes addressed were cover cropping issues, crop establishment, economics, soils, machinery and info exchange which included photos, dialogue, farm visits and meetings. Common queries and issues facing the forum members were analysed by the number of times a theme appeared along with the number of replies and views to the original post.

Results

Case studies

<u>Crop establishment and residues</u>

There are a large variety of crops grown from different families (figure 1, table 4) and most participants have a flexible rotation which is dependent on the soil conditions, weather and niche market needs - especially for seed crops.

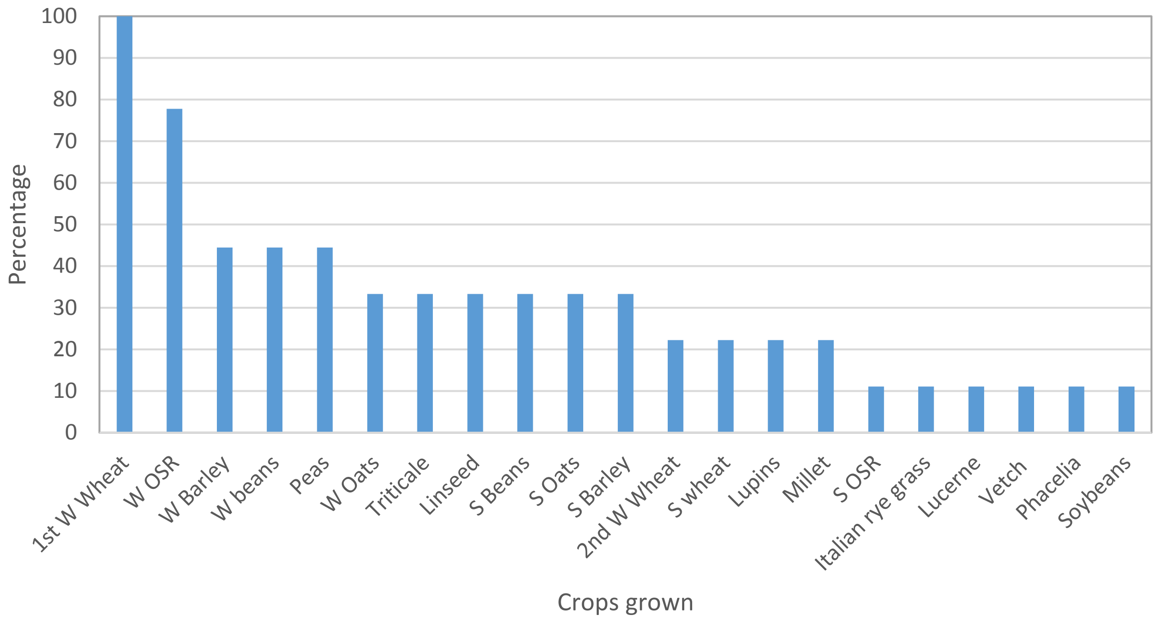

Figure 1: Percentage of respondents who have grown a particular crop.

Table 4: Average percentage of a particular family of crop grown from 9 case studies.

Taxonomic family	Percentage
Gramineae	54
Fabaceae	26
Brassicaceae	11
Linaceae	7
Boraginaceae	2

All respondents grew spring crops, with one aiming for 40% of spring cropping per year and another respondent growing two spring crops followed by two winter crops. The main reasons cited for spring crops were: spread work load, increase diversity, management of weed species especially blackgrass and helps with cash flow. Spring cropping was often preceded by cover crops established directly behind the combine.

The majority of respondents drill two weeks earlier for autumn crops and two weeks later for spring crops when compared to their previous tillage practices. However three respondents have a similar drilling date for autumn crops and two respondents have similar date for spring crops. Table 5 shows the differences in seed rate compared to previous tillage practices.

Table 5: Changes to seed rate since converting to ZT.

Change	Number of respondents	Comments
Increase	1 (+2)	1) One respondent increase seed rate by 5-10% for years 2-4 before returning to same seed rate 2) One respondent increased the seed rate for peas and linseed by 10%
Same	6 (+2)	
Decrease	1	1) More accurate seed placement

When establishing crops the cover crop and/or volunteers are desiccated but the timing of spray may either be before or after the crop has been drilled into stubbles left from harvest and/or cover crops planted. Two respondents graze cover crops pre drilling and then desiccate.

Seven respondents use a range of fertiliser sources to supplement artificial applications; AD waste, compost, Fibrophos and farm yard manure. Two respondents have not applied P&K for the past few years and one respondent has decreased P&K use by 80%. Three respondents apply minimal amounts of nitrogen or compost in autumn. One respondent blows calcium onto OSR seed to neutralise acidic chemicals produced by decaying residue.

Following harvest one third of respondents bale the straw, two respondents chop straw and two leave high stubbles (25- 30cm). Two respondents chop straw unless it is wheat or oat straw whilst another uses a stripper header occasionally. Four out of six respondents do not currently use a rake citing the following reasons: feels recreational, good residue spread achieved by combine, no advantage in pest and weed control. Two respondents felt using a rake helped with pest and weed control.

Cover crops

Cover crops are established by six out of nine respondents with another allowing volunteers to grow to provide soil cover. One respondent has stopped establishing cover crops as no benefits have been realised stating 'the bigger the cover crop the worse the cash crop' and that cover crops contribute to a later sowing date. One respondent is not convinced of the benefits of cover crops. Those growing cover crops have seen or believe the following are benefits: improve soil structure and texture, retain moisture, reduce soil erosion, control weeds and provide a habitat for beneficial insects. Those growing cover crops establish mixes to provide diversity and different rooting structures, with some not establishing any graminaceous species. One respondent establishes a cover crop immediately after harvest before an autumn cash crop.

Economics and machinery

Tine and disc drills were the main types of drill used and most respondents owned more than one drill.

Table 6: Drills used by case study farms.

Drill	Number
John Deere 750A	4
Weaving	2
Kuhn SD 4000	2
Great plains	2
Aitchinson Sim Tec	2
Moore Uni drill	1
McConnel shakerator combination	1
Kockling tine drill	1
Home built tine drill	1
Dale seed hawk	1
Bertini 22.000 triple disc	1
Amazone Primera (tine)	1

Median tractor horsepower across the nine case study farms was 145hp with a range from 100hp to 250hp. Large tractor horsepower were needed for other tasks such as grain carting.

Time to establish a crop is ≈ 22.5 mins / Ha from five respondents and costs ≈ £20- £25/ Ha. Respondents all noticed a decrease in fuel with the median average from five respondents' ≈ 5L/ Ha or between third and a quarter of that used previous to ZT. Five out nine respondents spend less on spray overall, with one respondent noticing a 20-30% decrease in spray cost, the remaining respondents have not seen a decrease in spray costs. Two respondents estimate that in the first year of conversion they saved £60,000 and £130,000 respectively through decreased costs in fuel, labour, and wearing parts. Seven respondents report no difference in yields, with one respondent noticing a decrease in years 1 to 3 before yields return and one respondent was unsure.

Weeds, disease and pests

All respondents believe overall weed incidence has decreased although six respondents cite species of brome as the most problematic weed. Blackgrass has been an issue for seven of the nine respondents however six respondents state that the issue is either declining or incidence is very low and the other respondent reports there has not been an issue with blackgrass for 2 years. Three of the seven respondents believe ZT is responsible for this decline in blackgrass for the following reasons: no disturbance of soil, rotation and spring cropping. Eight of nine respondents believe that a green-bridge does not exist due to a diverse rotation and beneficial fauna. Slugs remain the main pest except one respondent where the main pest is snails due to soil type. Five respondents believe the issue of slugs is unchanged or has decreased since converting to ZT due to natural predators, cover crop and the slug's preference for OSR.

Soil and the environment

All respondents have noted improvements to the soil especially in the following characteristics: structure, more porous, better aeration, an increase in fertility and change in colour due to soil organic matter. The majority of respondents do not think compaction is an issue, as soil is better able to carry weight of machinery with combines unloading on the headland. Two respondents remark that rutting is very rare and wheelings are barely noticeable, in one case spray passes are made in different tramlines until crop would be severely damaged. All respondents understand the importance of using the correct tyres and pressures.

All respondents have seen improvements in water infiltration: less wet spots, less water in tramlines, decreased formation of gulleys and cleaner water in ditches. Seven respondents' mole plough periodically, and two respondents have free draining soils.

All respondents have seen an increase in worm numbers (up to 140 worms/ m^2) and soil diversity. Respondents comment on the increase in wildlife especially farmland birds, pollinators and beetles thought to be due to improved habitat and food sources.

<u>Conversion to ZT</u>

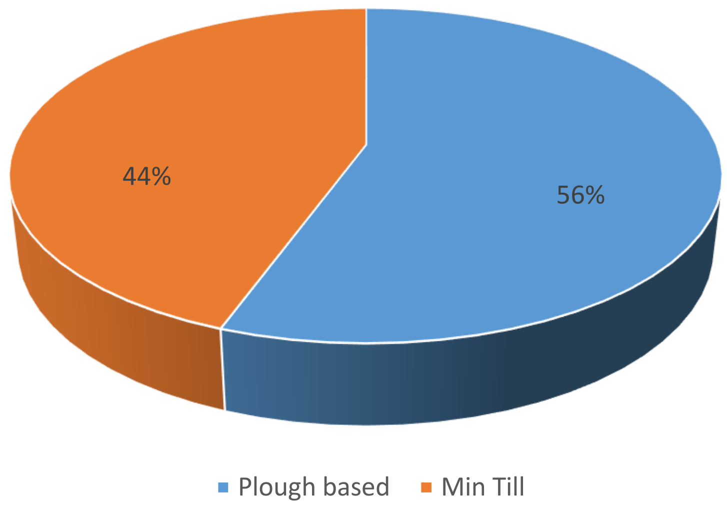

Figure 2: Type of tillage implemented in the year preceding conversion to ZT.

There were a variety of reasons given for the conversion to ZT and also barriers or possible reasons that farmers would not convert to ZT.

Table 7: Respondent's comments regarding reasons for, risks and barriers to conversion to ZT.

Reasons for conversion	Risks after conversion	Barriers to conversion
▪ Economics ▪ Lifestyle ▪ Improve soil ▪ Improved traffic-ability ▪ Better use of water	▪ Post drilling rainfall ▪ Weeds not managed by glyphosate ▪ Slugs	▪ Mind set – tradition ▪ Bank manager – risk to change ▪ Vested interests of industry in particular machinery and chemical companies – lack of research and knowledge ▪ Lack of understanding/ support from some industry professionals ▪ Other people's views, opinions and doubts

Before conversion to ZT all respondents had visited a number of farms, some abroad, that had successfully converted to ZT and spent the previous year researching ZT through reading literature and online forums. Respondents converted to ZT either over a number of years or in one year and recommend that the fields are level and ruts are removed before establishing a crop.

Online forum analysis - TFF

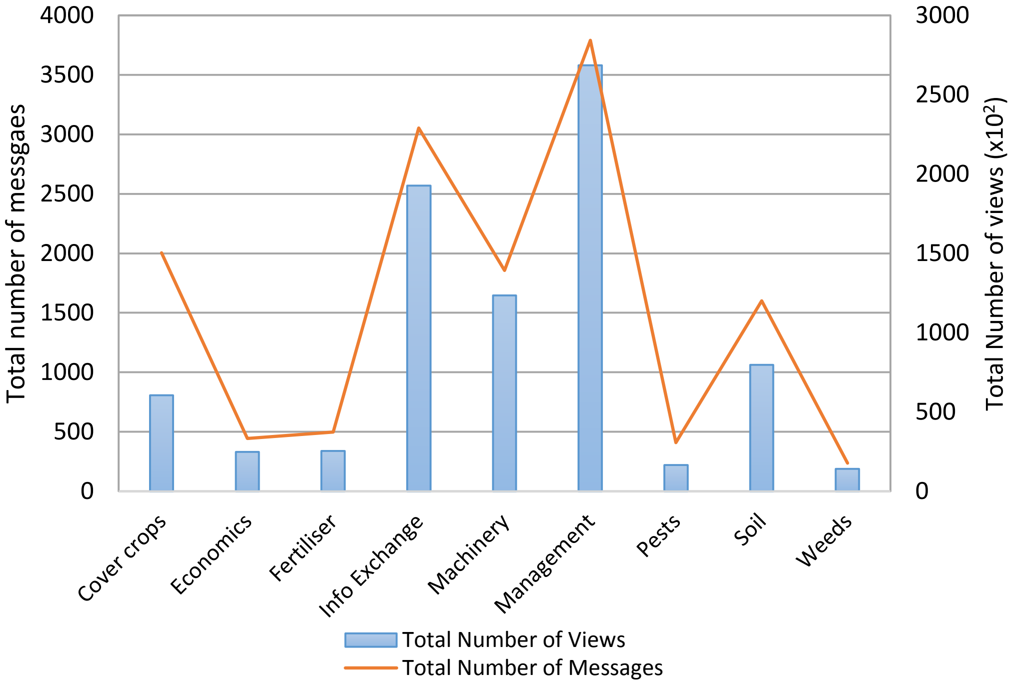

Figure 3: Primary themes of online forum discussion.

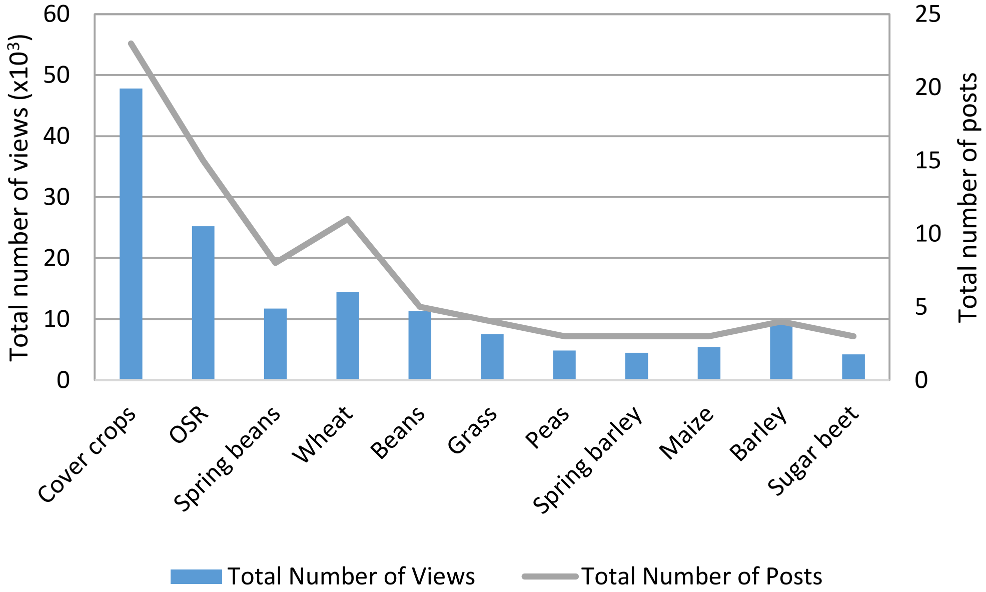

Figure 4: Secondary themes of crop establishment.

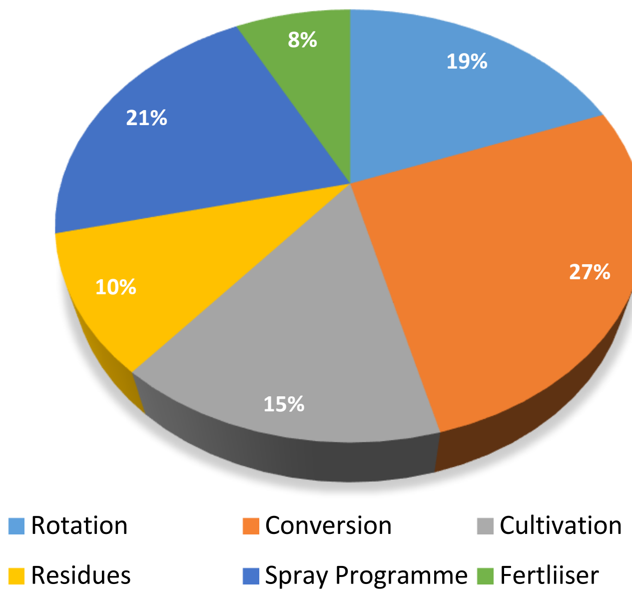

Figure 5: Discussion topics within the primary theme of management.

The null hypothesis that there is no difference between cropping and management practice discussion on the online forum is rejected as the chi squared value = 3.763×10^{-100} for 2 degrees of freedom ($p < 0.05$) which suggests that the discussion topics are independent. Therefore the alternative hypothesis is accepted, that there is a difference between cropping and management discussion. As the null hypothesis is rejected the difference between observed and expected results is significant. Discussion regarding the economics of cover crops is higher than expected whilst the economics of crop establishment is lower. Information exchange relating to cover crops is lower than would be expected whereas information exchange concerning crop establishment is higher than would be anticipated.

Discussion

Case Studies

Crop establishment and residues

The rotation that ZT farmers grow is more varied and generally longer than conventional agriculture, with a wide range of species of crops grown (figure 1, table 4) including many spring varieties. Respondents grew crops according to prevailing conditions or specific markets rather than a set rotation. Famers practising tillage tend to have a fixed and shorter rotation due to the economic pressures (HGCA, 2014). Spring crops are grown for a number reasons and are seen as almost essential in ZT systems especially in the control of weeds and helping to increase soil diversity to improve the overall soil ecosystem.

Crop residue management was dependent on whether livestock was reared on the respondent's farm or locally and if this was the case straw would be baled, if not respondents chopped the straw or left tall stubbles. Literature (Rydberg, 2010) suggests that if straw is left on the field then yields decrease under ZT compared to mouldboard ploughing, however it is not specific if the straw is either left standing (25 -30cm) through the use of a stripper header or chopped and spread by the combine. It could be expected that chopped straw on the soil surface has a greater phytotoxic effect due to greater likelihood of decaying residues in contact with the seed, this is particularly a problem with soils that are wet and anaerobic. All respondents are aware of the phototoxic effect and it was discussed on TFF under the title 'The Two Simon's Theory' where online members debated which seeds are most susceptible and the types of decaying residues with the strongest phototoxic effect. A solution one respondent implements to counteract the acidic toxins is to blow calcium onto OSR seed at drilling which is a small and susceptible seed to phytotoxcity.

Two-thirds of respondents establish cover crops for erosion prevention and for the properties that green manures and catch crops offer as defined in the literature. Some respondents do not include graminaceous species in cover crop mixes and rely on broadleaved and legume species to condition the soil. Respondents established mixed species cover crops which corresponds with the published literature of multiple benefits and that mixes can be designed to meet agronomic objectives and improve growth of the following crops (Schaupp, 2014).

The timing of cover crop termination is essential to provide the correct conditions for crop entry with soil moisture and temperature a primary concern for spring crops. Most respondents drill two weeks later in the spring to allow for the soil to dry out and warm up, especially following over-wintered cover crops. Some respondents drill two weeks earlier in autumn to allow more vigorous growth to occur before the winter; under ZT nitrogen is mineralised at a slower rate when compared to tillage (Blevins & Frye, 1993). Some respondents will apply a small amount of nitrogen at drilling to mitigate this effect.

Economics

The economic advantages of ZT are decreased costs for fuel, labour and machinery parts but also a reduction in the establishment time which allows for a greater productivity and better timeliness of operations which is reported by all the respondents. The reduction in operations and time required for establishment has improved the lifestyle of the respondents and their employees. The majority of respondents have found that spray costs have decreased mainly because they are able to forego some expensive applications of autumn herbicides.

Yields of ZT were recently reported to decrease when considered globally across many crop species (Pittelkow, et al., 2015) however the case studies in the UK report that there has not been a decrease in yield that could be attributed to ZT and that yields were similar to previous yields when tillage was practiced. Some respondents noted that yields may initially decline for 2-3 years before returning to comparable yields of previous tillage practices as the soil structure needs time to adapt. A respondent suggests that the higher the intensity of tillage in the years immediately before conversion the more likely the yield decrease due to lower organic matter in the soil.

Tractors are generally smaller on ZT farms at a median size of 145hp compared to the industry average of 155hp (Agricultural Engineers Association, 2015) which is growing at a rate of $\approx$ 2% a year. Larger tractors on ZT farmers were needed for carting operations and not crop establishment where draught requirement is low so smaller, lighter and cheaper tractors can be used which have a smaller impact on the soil.

Two-thirds of respondents had at least two drills for use depending on seed to be sown or the soil conditions in a particular year. Disc and tine based drills create a different soil environment for the seed and tend to be suited to different conditions. Disc based drills are better able to manage standing crop residues and trash whereas tine based drills act as row cleaners moving decaying crop residues from near to where the seed is to be placed minimizing the phytotoxic effect.

Weeds, disease and pests

The experiences of the respondents regarding weed incidence is supported by literature with a decrease in overall weed numbers (Popay, et al., 1994) and that species of brome are the main problem (Basch *et al.,* 2015). Basch *et al*, (2015) report that annual grasses such as blackgrass are more prevalent under

ZT but six respondents have found that since converting to ZT the incidence of blackgrass has declined; this is the subject of recent trial work by Agrovista (Hemmant, 2014).

The green bridge effect is a concern when leaving residues and growing cover crops between cash crops, however all respondents do not believe the green bridge effect to be a problem and this view is supported by research for some diseases. Incidence of eye spot, take-all and club root all decrease under ZT (Brautigam & Tebrugge, 1997) (Ekeberg & Riley, 1997) due to organic matter and beneficial predators that control aphid vectors. The risk of septoria increases with ZT (Hershman, 1992) however respondents did not notice increased incidences of the foliar disease which some respondents believe is due to the wide crop rotation grown.

Slugs are the main pest for respondents, however the issue is manageable and in some cases is declining due to natural predators like the carabid beetles which are more prolific on ZT soils (Kromp, 1999). Some respondents have observed that slugs prefer to feed on OSR and therefore leave volunteer OSR to grow as food for the slugs and desiccate with a selective herbicide following wheat establishment.

Soil and the environment

The change to ZT soils is well documented and researched with all the associated benefits reported realised by the respondents. The structural properties of the soil can take 3-5 years to develop which coincides with the reported decrease in yields. During this time period macropores become vertically aligned in the soil that confer many desirable properties such as increased water filtration and bearing capacity. Respondents report that rutting is rare and traffic-ability improves over time with water better able to infiltrate the soil reducing erosion. Worm populations in ZT increase hugely due to the undisturbed soil profile and continuous food source provided by the crop residues; these worms condition the soil and are partly responsible for the improved structural properties along with rooting of crops.

Conversion and barriers to ZT

Prior to conversion to ZT most respondents spent a year researching the practice through reading literature, including online forums and visiting farmers who have implemented ZT. Respondents often faced doubt from neighbouring farmers when they converted and found that some industry professionals were unsupportive or lacked sufficient understanding of ZT. On the whole respondents felt that the vested interests of the machinery and agro chemical manufacturers hindered the development and knowledge transfer of ZT in the UK. ZT may result in reduced profits for machinery manufactures' as tractor sales and size decreases, cultivators become redundant and some agrochemicals may not be needed. Mindset and farming tradition especially in family farms with a long history continues to be a reason why ZT is not taken up, older generations may see accepting ZT as an admission that their own methods of farming were incorrect. Adopting ZT can be risky especially in the first few years as new knowledge is required and it is a different approach to farming with a lot of money invested which the bank manager may not support. Some respondent's approach to conversion was cautious with a gradual increase of farmed area under ZT and a gradual progression towards decreased tillage intensity (plough – maxi till- min till – ZT) whilst others converted the whole farm from ploughing one year to ZT the next year. The respondents have varying lengths of experience practicing ZT that include the wet and challenging years but all have been successful due to their thorough research before conversion. All the respondents are prepared to experiment and try new ideas and readily share information gained with others which helps further their own progression of ZT.

Online forum analysis - TFF

The online forum, TFF is a very useful platform for sharing information relating to all aspects of farming. Figure 3 shows that management, information exchange and machinery in the direct drilling section were the main areas for discussion with the highest number of views and messages. The management theme (figure 5) is broken down further with discussion surrounding conversion to ZT accounting for 27% of the messages. This suggests that online forum members keenly debate and share knowledge regarding conversion to ZT reporting accounts of their own experiences and ideas for best practice to aid other members who may not be as experienced. The spray programme that members implement accounts for 21% of messages under the management theme that included topics of when to best terminate cover crops, but also concern of the effects of residual chemicals that recommend cultivation is needed to prevent damage to following crops. Rotation accounts for 19% of the messages in the management theme as members understand the importance of a rotation and look to find crops that fit their system, often members are looking for feedback on the rotation and crops they intend to establish.

There is discussion surrounding establishment of a wide variety of crops with messages and views regarding cover cropping double that of wheat. This implies that members are interested in cover crops and are using TFF to gain information, as there is little literature produced for farmers and it is a relatively new concept in the UK when compared to wheat which has growth guides and is well researched. The intensity of discussion surrounding cover crops results from respondents differing views regarding the use of cover crops from very beneficial to those who are not convinced of the benefits. The Chi square analysis indicates that the economics of cover crops is discussed more than would be expected compared to general crop establishment as online forum members try to form an opinion on whether cover crops would be beneficial to their system.

Conclusion

In conclusion the case study supports the research of decreased costs associated with establishment with added cost savings on spray due to decreased herbicide application. Respondents report that there is not a decrease in yields that could be attributed to ZT, however there is agreement with the literature that yields may decline initially after conversion to ZT. Literature also supports the respondent's view that disease prevalence and the green bridge effect are not a problem, but rather that certain diseases can decrease under ZT management. Contrary to the literature respondents report an improvement in blackgrass control using ZT. The improvement of soil quality through ZT and the associated benefits of water quality and infiltration is reported in the literature as well as the improvement in wildlife diversity. Cover crops remain an evolving aspect of ZT practice in the UK with their benefits and use still debated. The barriers to conversion to ZT reported in literature are shared by the respondents who see mindset, tradition and lack of knowledge or teaching still the biggest barriers to the development of ZT.

The study highlighted that there needs to be further research into the use of cover crops and their benefits, especially concerning the varieties which would be best integrated into UK farming systems. There could be further research into how best to mitigate the phytotoxic effect on crops through farming methods. Limitations to the research conducted is that more farms could have been included to capture a greater amount of information, this would be especially useful in the quantitative aspects of the study relating to the economics of ZT. A limitation of the forum analysis is that the posts are open to interpretation especially if content related to more than one theme of classification.

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