Title: Wheat straw availability for bioenergy in England

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Abstract

In an effort to meet energy demands while reducing carbon emissions, crop residues, such as wheat straw, have been investigated for their use as feedstock for biofuel production. In order to identify the feasibility of utilising crop residues as bioenergy feedstock, a postal survey was conducted to determine current farm business wheat straw use, destination and potential future supply. The survey responses showed a bias towards larger, more commercially-minded farms, therefore capturing a large area of straw production. Results demonstrated a wide range of responses to both current straw use and potential for the supply of straw to different markets in the future. Interestingly, even for a very generous payment for straw, 28.5% of straw currently chopped and incorporated would not be sold, suggesting that straw supply for bioenergy feedstock is likely to be more limited than previously assumed. However, higher prices for straw would encourage farmers to explore ways of increasing straw yield.

Highlights

- Straw supply for bioenergy more constrained than previous indications
- East of England farmers least likely to supply straw for bioenergy purposes
- Crop management changes could increase straw supply but to a limited extent

Keywords: Bioenergy; Wheat; Postal survey; Straw

Acknowledgements: This work is part of TJT's PhD project funded by the Home Grown Cereals Authority (RD-2010-3741) and the University of Nottingham. The data collected as part of the Farm Business Survey was supported by the Biotechnology and Biological Sciences Research Council (BBSRC) Sustainable Bioenergy Centre (BSBEC), under the programme for 'Lignocellulosic Conversion to Ethanol' (LACE) [Grant Ref: BB/G01616X/1].

Introduction

Second-generation biofuels derived from crop residues provide a potential means of reducing reliance on oil-based fuels in the transport sector (IEA, 2010). In the UK, and other northern European countries, wheat straw is one of the greatest potential sources of feedstock for these biofuels. Production of straw in the UK outweighs demand and a large proportion is chopped and incorporated into the soil after grain harvest (Copeland & Turley, 2008). However, the amount of straw available that could be available for biofuel production is uncertain and estimates of straw availability vary depending upon methodological approaches adopted and study periods examined; given its low economic value relative to grain output, official data on straw production do not directly exist. Crucially, one of the most important aspects of developing a second-generation biofuel sector requiring investigation is the extent to which farmers are willing to supply feedstock (Thivolle-Cazat et al., 2013).

Willingness to supply straw as feedstock will vary greatly among farmers, with some unwilling to sell straw at any price (Tyndall et al., 2011). Glithero et al. (2013a), in surveying arable farmers in England, found a third would not supply wheat straw for bioenergy, and in a survey of farmers in Missouri and Illinois, Altman et al. (2013) found that 42% and 39% of farmers respectively, were not willing to make their hay, wheat straw or corn stover available to sell in a biomass market, though it is unclear if they were already using their crops/hay or residues for other uses. Giannoccaro et al. (2017) found 31% of survey participants in Apulia (Italy) were unwilling to supply straw to a bioenergy market.

There are many factors that influence a farmer's decision to supply straw including: the price offered for the straw; the need to return crop residues to maintain soil health; timeliness

considerations regarding fitting in baling operations around other farm operations; soil compaction from baling; access to markets; and contract terms (Glithero et al., 2013a).

Considerations about soil health are often incorporated in estimates of straw availability (e.g. Searle & Malins, 2016, factor in an average of 3.7 t ha^{-1} crop residue remaining on the field across EU countries). Returning crop residues to the soil is recognised as providing important services including reducing erosion, improving soil structure and providing nutrients (Searle & Bitnere, 2017); however, the amount that needs to be left on the field to maintain soil health is to some degree uncertain and will be affected by location, soil type, cropping system and existing soil organic matter levels. It is unclear whether straw remaining on the field as stubble is sufficient to meet those requirements or if farmers would need to leave additional straw on the field or alternate between harvesting straw and chopping and incorporating it in the crop rotation.

To some extent, straw availability estimates can take account of access to markets and the amount that must be incorporated to maintain soil health; however, beyond these there is difficulty in incorporating farmer willingness to sell into estimates of straw availability. Some studies assume that farmers will supply feedstock at the breakeven production price (e.g. Gallagher et al., 2003) or for the breakeven price plus a percentage to cover risk, management and profit margin (e.g. a 15% margin in MAFRD, 2014). Others use arbitrary assumptions for farmer willingness to supply straw, such as Petrolia (2008) who assumes a 50% farm participation in feedstock supply. Due to simplified assumptions such as these, it is possible that previous biomass feedstock availability has been overestimated (Tyndall et al., 2011). However, as considerable policy and research investment is based on estimates of energy potential from biomass sources, and in particular from by- or co- products from agricultural production, accurate estimation of biomass supply is vital in order to accurately

inform the bioenergy debate. For example, resource availability, which included feedstock availability, was one of the dominant sources of uncertainty in entrepreneurial decision making with regards to an emerging renewable energy technology (biomass gasification projects in the Netherlands; Meijera et al., 2007). A greater understanding of farmer decision making in general, in particular to understand non-economic influences on decision making, is of great interest to policy makers in government (Edwards-Jones, 2006); being able to better predict straw availability through improved understanding of farmer willingness to sell feedstock could significantly influence policy decisions, industry investment and associated impacts on biofuel availability.

In addition to understanding farmers' willingness to supply straw from current production levels, farmers may also adjust their straw production practices in response to potentially higher straw prices resulting from changes in the straw market. Given that modern plant breeding and agronomic practice has led to production of shorter straw in cereal crops, Townsend et al. (2015) reviewed the concept of a dual-purpose wheat cultivar that was optimised for grain for feed or food markets and straw for the biofuel market. Management practices that could influence straw yield were identified; however, given the lack of scientific focus towards increased straw production, there is little research to support these practices. Hence, although potential means of increasing straw yield per area exist, it is uncertain if farmers would adopt these practices, especially given the relative grain-straw market prices, which favours techniques that partition biomass to the grain at the expense of the straw. Glithero et al. (2013a) found that farmers were more interested in contracts that specified straw supply based on area rather than by weight, which might influence decisions about whether it is in the farmers' interest to increase straw yields. It is unclear the terms of contracts currently available to farmers for straw for bioenergy in the UK as publicly available information on straw contracts for energy is not something readily available,

suggesting these might be bespoke. Nevertheless, in the presence of enhanced market opportunities for straw flowing from demand for second generation biofuels, farm-level adaptation strategies are likely to include changes to the amount of straw baled and sold, and agronomic or management changes favouring increased straw yield, or straw harvested, per unit area. Knowledge of farm-level adaptations, capturing these production and market changes, represent key policy questions. Consequently, the objectives of the study were to better understand farmers' intentions regarding current and future straw supply, drawing upon a structured postal survey methodology.

Methodology

Survey questionnaire

The postal survey questionnaire followed Dillman's tailored design survey protocols (Dillman et al., 2008). Pilot work took place during the development of the questionnaire involving discussions with farmers and individuals with prior experience of conducting farmer surveys. A pre-paid addressed envelope was provided for respondents to return the survey questionnaire. The survey questionnaire was sent out in December 2012[1]; this time of year was chosen to maximise response rate as it is a less busy period for arable farming operations.

The survey population was focused on the eastern side of England as this region accounts for the largest area of arable production in England, and is additionally where the greatest straw surpluses are found (Copeland & Turley, 2008); this region is, therefore, the most likely site for a biorefinery (Glithero et al., 2013b). All counties within the North East, Yorkshire, East of England, East Midlands, and South East of England Government Office Regions (GORs) were surveyed. The survey frame was based on addresses from business directories (Yellow Pages and the Thomson Directory). A total of 2,000 questionnaires were sent out; 1,245 addresses were collected from the Thomson Directory with the Business Activity class 'Farming – Crops' and 755 addresses from the Yellow Pages with the Business Activity class 'Farmers'. The addresses available were limited for these farms with only 36,877 addresses for the UK when the Yellow Pages classification "Farming" was selected against an estimated 105,449 holdings in England alone in 2010 (Defra, 2011). The sample of 2,000

[1] Since the survey was conducted there have been no structural changes in crop or input prices, suggesting that the responses would not be significantly different if the survey was conducted in 2017.

farmers represents approximately 4% of the farms[2] in these regions (Defra, 2011). Due to the limited information on the farmers contained in these directories, not all farms would be wheat producers, thus limiting the potential responses. The returned surveys purposefully did not require contact details or details about finances from respondents to be provided in order to minimise barriers to survey completion and return; however, this meant it was not possible to identify non-respondents and this prevented unreturned responses from being followed up. The implication of these choices when constructing the questionnaire will be explored in the discussion.

Survey questions

The relevant questions from the questionnaire are presented in supplementary material (**Supplementary 1**). The survey questionnaire asked about the county where the farm was located, the age of the farmer and the size of the farm. The respondent was asked to provide information on the crops grown for harvest in 2012 and the livestock held on the farm that year. They were asked whether they had any other enterprises on farm though this was not given financial quantification preventing in-depth analysis. The questionnaire had a Likert-scale rating question for the importance placed on farming objectives.

Respondents were asked about their uses of the wheat straw from the 2012 harvest. They stated the area of land given to each wheat straw use. This means straw use was based on area harvested rather than actual straw yields; this is a more practical way of comparing use as yield would not have been quantified for straw being chopped and incorporated, and not necessarily for straw being baled and sold. It is acknowledged that when straw is baled that

[2] As discussed in section "Survey responses" there are differences between *farms* and *farm holdings* with a farm potentially comprising multiple *farm holdings.*

there will still be straw remaining on the field (i.e. stubble, leaf material and chaff) that will be returned to the soil.

Some assumptions had to be made to analyse the straw-use data. Some answers were incomplete for the question about wheat straw from the 2012 harvest and hence straw uses had to be approximated from other data. For example, when the proportions of straw used did not sum to one, unproportioned use was allocated to 'straw chopped and incorporated'. This was because it was assumed that the farmers would have a much clearer idea of the amount of straw they had baled than they had incorporated. When residues from other cereals (e.g. barley, oats) were included and it was unclear what each straw type was used for, the same proportions of total residue for each use were assumed for the wheat straw.

Three questions examined potential future straw supply: respondents were asked at what price they would start managing their wheat crop to increase straw yield, whether they would be willing to sell extra straw if the price was to increase to £100 t^{-1} baled (market price at the time of the survey was approximately £40-60 t^{-1}, Anon, 2015) and whether respondents would utilise any management practices to increase straw yield should the price reach £100 t^{-1} baled. The questionnaire also gave respondents the opportunity to make any additional comments about straw supply; this data was not analysed but some comments from this section are drawn upon in the discussion.

Sample

The survey received 516 usable responses. To test for response and sample bias, the data were compared to sample population data known *a priori*. Comparison with Defra's 2010 June survey (Defra, 2011) demonstrated that survey response farms were much larger on average than in the general population; this bias towards larger farms suggests the findings

are not representative of the farm population as a whole; however, the responses are likely to be more representative of the farmed area. Diversification enterprises were found on 41% of the surveyed farms compared to 24% of commercial holdings in England in 2010 (Defra, 2011). These findings support the idea that the phone directory sample frame is biased towards more commercially-oriented farmers. In the postal survey, the most common age group was 55-64 years old (n = 171) closely followed by 45-54 years old (n = 151) compared to the mean age of UK farm holders in 2010 of 59 years old (Anon, 2012). For UK farms, 14% of farm holders were under 45 years old in 2010 compared with 13% of respondents in this study though this is for the whole of UK and the respondents to the survey were not necessarily the farm holder.

Issues with postal surveys such as representativeness and whether data returns reflect respondents' real intentions have been addressed in the literature. Having a sample frame that contains the whole population is not always possible as access to complete lists of British farm addresses is not possible (Mattison & Norris, 2007). Business directories are frequently used for creating a sample frame (e.g. Morris et al., 2000; Carter, 2001; Mattison & Norris, 2007; Lobley & Butler, 2010); however, this leads to coverage error because these directories do not contain the entire population. For example, life-style farmers and economically constrained farmers appear to be less likely to be listed in the Yellow Pages (Burton & Wilson, 1999). This can lead to an overrepresentation of larger farms within the sample frame (e.g. as seen in Morris et al., 2000, and Lobley & Butler, 2010); however, the authors argued that this is acceptable as the survey respondents account for a large proportion of the land and resources and these commercial farms are of greater interest to these types of studies.

Data sorting

Farms were divided into groups based on regions, farm type, farmer age and farm size (given as total farm area). For farm region, not all farms could be characterised as some respondents did not include location information whilst others were spread over multiple counties and regions (i.e. when multiple farm holdings made up a single farm); these farms were therefore excluded when undertaking comparisons among regions. Some responses did not include farmer age details, and these were therefore excluded from comparisons between age categories.

The Farm Business Survey methodology was used to determine farm type on the basis of economic output from the enterprises or group of enterprises. When a farm business derives at least 2/3rd of its output from an individual enterprise or grouping of enterprises (e.g. combinable crops output for the Cereals farm type) the farm business is classified as a particular farm type; in the absence of the 2/3rd output threshold being met from a specific enterprise, farms are classified as Mixed. The value of each farm enterprise (given as a standard outputs) was estimated using information collected in the survey and the relative values of these enterprises was used to establish a farm type. Farms were divided into Cereal farms (where cereals and combinable crops accounted for more than 2/3rd of output), General Cropping (where arable crops accounted for more than 2/3rd of output, excluding farms classed as Cereal farms) and 'Other' (aggregation of all other types of farm due to limited representation from these individual farm types; all these farms combined cropping with livestock).

Statistical analysis

Statistical analysis used GenStat (15th edition, VSN International Ltd). Chi-square test of independence was used to test the hypothesis that there is no association between group

descriptors (e.g. farm size groups) and stated actions or attributes. Some data was grouped to avoid having more than 20% of the expected values lower than five. In particular, Likert-scale ratings for *very unimportant* and *unimportant* were aggregated with *neutral*, as these were only very rarely selected. To analyse straw use using Chi-square, respondents were placed into categories based on the percentage of their total straw chopped and incorporated (0%; 1-50%; 51-99%; and 100%). For straw price comparisons, ANOVA was used to compare the groups after the data were checked to see if they met the assumptions of normality of residuals and constant variation. An alpha level of 0.05 was used for all statistical analyses.

Comparison to previous survey results

Responses from this survey were compared to survey data collected as part of the programme for 'Lignocellulosic Conversion to Ethanol' (LACE) in conjunction with the Farm Business Survey (Glithero et al., 2013a-c). Interviews were conducted with 249 farmers representing a range of farm types and sizes across all GORs in England.

Where there was overlap between the surveys (straw use per region and farm size, management decisions for increasing straw yield) results were compared between surveys. Factors that contributed to the proportion of straw chopped and incorporated were also analysed from unpublished data from that survey.

Results

Straw availability

Of the 97,958 ha of wheat straw covered by the survey results, 53,475 ha (54.6%) of straw was chopped and incorporated, 8,536 ha (8.7%) was baled for on-farm use, and 32,897 ha (33.6%) was sold (**Table 1**). The remainder (3,050 ha; 3.1%) was used for other uses such as for covering carrots and straw-for-muck agreements (where straw is given to livestock farms in exchange for manure).

Chi-square tests demonstrated that farm size, region, and type, and farmer age all had significant impacts on the amount of straw chopped and incorporated (P <0.001; **Table 2**). The greatest proportion of straw chopped and incorporated was in the East of England. The North East had the lowest proportion of straw chopped but the number of responses for the North East was much lower than with other regions, possibly highlighting a geographical sample bias. A greater proportion of straw was incorporated for Cereal type farms. *Other farms* tended to use all their wheat straw on-farm. Straw incorporation varied among age group categories; excluding the 35-44 year old age category, the proportion of straw chopped and incorporated increased with age whilst the proportion of straw baled, sold or used on farm tended to decrease. Comparing straw use among different farm size classes suggests that the proportion of straw that is incorporated tends to increase with increasing farm size. Farms up to 300 ha were more likely to bale all their straw (i.e. not chop and incorporate any of it) than farms over 300 ha. Farms larger than 300 ha were more likely than farms under 300 ha to chop and incorporate the majority (50-99%) of their straw though there is no farm size group more likely to chop and incorporate all their straw.

Wheat straw management

Supplying additional straw

If the straw price reached £100 t^{-1}, 231 respondents (44.8%) said they would sell more straw; 121 respondents already baled all their straw and used it on-farm or sold it; 110 respondents would not sell any extra straw; 45 respondents did not answer the question; whilst nine noted that they did not know (this was not given as an option so a greater number of respondents might have selected this if it had been included in the questionnaire). The respondents unwilling to sell extra straw collectively accounted for a total of 15,255 ha of chopped and incorporated straw (28.5% of all chopped and incorporated straw from all survey respondents). This suggests that even for a very generous price for straw, significant amounts of straw that could be baled will not be sold.

When considering farms that had additional straw (i.e. straw that is currently chopped and incorporated), the likelihood to sell extra straw did not vary with farm type, farmer age, farm size or region though there was a trend for farms in the East Midlands to be willing to sell extra straw with those in the East of England less willing to sell extra straw (**Table 3**). When considering willingness to supply extra straw and farmer attitudes (**Table 4**), respondents who were unwilling to sell extra straw were significantly more likely to rate *land stewardship* ($P = 0.010$) and *family objectives and succession* ($P = 0.030$) as very important. They were also more likely to rate *quality of life* as very important ($P = 0.017$). *Maintaining the environment* was not significantly different between groups but there was a strong trend for those who were unwilling to supply extra straw to rate it as very important.

Managing for straw yield

Over half (276, 53.5%) of the respondents provided a price per tonne of straw at which they would start managing their straw for increased straw yield. Of the remainder, 21 respondents

said they would not manage their straw for any price; 37 said they did not know and, even though it was not given as a response option, one respondent said that they already manage their wheat for straw yield. The average price given at which positive straw management would occur was £90.86t^{-1} but with large price variability around this mean (**Fig. 1**). There were several very low values (e.g. £10, £15), which are lower than estimated breakeven prices for straw (e.g. Copeland & Turley, 2008). Other prices were very much higher (two prices, £500 and £1,000, were excluded from the analysis). The interquartile range was £50 to £100. Price did not significantly vary with farm size, farm type or region (**Table 5**). Straw price response did, however, vary with farmer age (P = 0.004). Younger farmers wanted more money for managing wheat crops for higher straw yield with the amount of money decreasing with increasing age.

Respondents were asked which management practices farmers would employ if the price of straw were to increase to £100 t^{-1} (or £162 ha^{-1} in the swath representing an equivalent price to baled straw, accounting for baling costs). Of the 381 respondents who answered this question, 114 respondents said that they would not utilise any management practices whilst a small number of farmers (10) responded that they were uncertain what they would do. The remainder answered that they would employ at least one straw management technique.

The intention to utilise new management practices did not relate to farm type (**Table 6**) or farmer age but there was a trend with farm size for smaller farms to favour using management practices whilst larger farms did not. There was a significant difference with region (P = 0.025) with the East of England less likely to use management practices whilst the North East was more likely to.

Changing the cultivar to a higher straw-yielding cultivar was the most popular straw management change with 206 respondents (40% of all respondents) willing to employ this practice (**Fig. 2**). The other management practices varied from 39 to 80 respondents selecting each. Of the respondents who selected one of the other management practices, 80% of them had also selected growing a cultivar with higher straw yield. A few respondents suggested that they would lower the cutter height to increase straw collection; this may have been selected more frequently had it been given as a pre-set option.

Unpublished data from the on-farm survey from Glithero et al (2013a-c) found that 20% of farmers that use wheat straw on their farms would grow longer-strawed wheat cultivars should the price increase to £100 ha^{-1}.

Comparison to previous survey results

In the on-farm survey presented in Glithero et al. (2013a-c) it was found that more straw was chopped and incorporated, and less straw was sold or used on-farm, compared to the postal survey presented here. This was true for all regions except East of England where straw usage was similar between the surveys. In unpublished data from the on-farm survey utilised by Glithero et al. (2013a-c), on average 46% of straw was chopped and incorporated on Large farms but only 37% was incorporated on Small and Medium farms, where farm size was determined based on estimated standard labour requirements rather than farm physical size.

Drawing upon previously unpublished data on the reasons why respondents chopped and incorporated straw from Glithero et al.'s (2013a) study offers some insight into the supply of straw. These data reveal that the main reasons given for straw incorporation for large farms were timeliness concerns and perceived benefits of straw incorporation. The lower supply from large farms did not appear to result from a lack of a market, as very few respondents

gave this as a barrier to supply. Respondents with smaller farms tended to give a greater number of reasons than those from larger farms; they were more likely to cite lack of equipment, concerns about contractors and perceived benefits of incorporation, and soil compaction concerns from baling as reasons why they did not bale all their straw. A similar proportion of farms from small, medium and large farmers cited timeliness concerns as a reason why they did not bale all their straw. However, although these reasons show why farmers are not baling all their straw it does not show what proportion of straw is being chopped and incorporated because of each specific concern.

Discussion

Straw supply

The postal survey found that 55% of wheat straw was chopped and incorporated in 2012, which was greater than the amount chopped and incorporated in 2010 in all regions of England, apart from the East of England where the same amount of straw was chopped and incorporated as identified by the on-farm survey. Variation in weather patterns, such as rainfall (Engel et al., 2003), can influence straw yields; in 2010, there was low rainfall during the spring (Met Office, 2013a) that may have led to lower straw yields meaning more hectares would have needed to be harvested to meet demand. Conversely, in 2012, there was a wet spring (Met Office, 2013b), which may have led to high straw yields. Field experiments presented in Townsend et al. (2017) showed much higher straw yields in 2012 than 2010. However, although yields were higher in 2012, based on comments made by survey respondents, the wet weather during the autumn (Met Office, 2013c) discouraged some farmers from baling due to concerns about both timeliness of establishing the following crop and soil compaction resulting from baling on wet soil. It is unclear why the rates are the same in both years for the East of England; one logical explanation for this being the overall lower annual straw demand, and associated level of straw baling in this region.

The results of potential straw supply are important as operating a bioenergy facility at below capacity is likely to be economically unfeasible meaning the capacity of straw-fuelled bioenergy in the UK must be effectively determined by the minimum availability of straw. This requires quantifying straw supply over multiple years. It is interesting to note that Scarlat et al. (2010) specifically suggested basing bioenergy capacity on the minimum amount of feedstock available in an area.

Another reason for differences in the proportion of straw chopped and incorporated between the survey years is likely to be due to differences between the samples in the studies, with the 2012 postal survey biased towards larger, more commercially-minded farms. The positive correlation between the size of the farm and the amount of straw chopped and incorporated supports this hypothesis.

We had two hypotheses for why larger farms incorporated a greater amount of straw: insufficient demand for the straw or timeliness constraints requiring quick establishment of the following crops. In the data presented in Glithero et al. (2013a), growers on Large farms did not state that insufficient market demand was a barrier to selling straw; however, this sample did not include Very Large farms (where five or more full-time equivalent workers are required) that may have found that market demand was too low to sell all of their straw. Other authors have suggested that larger farms tend to have greater pressure to maintain timeliness of crop operations (Melander et al., 2013); although our study demonstrates the proportion of farmers expressing timeliness concerns were even across farm sizes, it could be that these concerns were greater on larger farms and led to a greater proportion of straw being chopped on larger farms than smaller farms during the wet harvest of 2012.

The largest straw surplus was identified to be in the East of England, which suggests this would be a good location for a bioenergy plant. In fact, the majority of the current and planned capacity for straw-burning bioenergy is in the East Midlands and East of England. However, although not significant, there was a strong trend for farmers in the East of England to be less willing to supply straw should it reach a price of £100 t^{-1}. This might mean less straw is available than expected in this region. Reasons for this could be that historically straw supply from this region has been low meaning there is a lack of experience in supplying straw; in part this lower demand is argued to flow from the low density of livestock farms in

the East of England (Defra, 2013) but also because there is less manure available hence farmers value the return of organic matter through straw incorporation. Moving to supplying straw potentially involves investment, such the purchase of new machinery, hiring additional labour, learning costs and changes to existing farm practices, and this would be particularly acute where there is no existing experience of supplying straw.

Increasing straw yield

The average price farmers would be willing to start managing their wheat for straw yields is approximately £90 t^{-1}, which is £40 above the average minimum price farmers were willing to sell their straw for bioenergy use, identified by Glithero et al. (2013a). However, there was considerable variation in the price that farmers were willing to manage their straw for. Farmers aged 45 and older required a lower price to manage for increased straw yield. This greater willingness to change growing practices is contrary to the generally accepted idea that younger people are more willing to innovate or change practices (e.g. Rogers [1995]'s Diffusion of Innovations). From the data collected it is unclear why this is the case.

An increase in the price of straw might also influence farms with both cereal crops and livestock to manage their wheat for increased straw yields so that they reduce their costs from having to buy straw in at higher prices.

With respect to potential agronomic and management changes, the clear preference for farmers was to grow cultivars with greater straw yields, which is also supported by results in Wilson et al. (2014) with respect to livestock farmers' attitudes towards an increased straw price. In the current study respondents had concerns about increased lodging risk from higher straw yields and this might be reflected in a lower selection rate for not using plant growth regulators (PGRs). Even though growing cultivars with higher straw yield was the most

popular choice this might not be feasible; Townsend et al. (2017) found similar straw yields for contemporary commercially-grown cultivars and achieving greater straw yields required growing older cultivars that were characterised by lower grain yields from greater biomass partitioning towards straw production. Other proposed management practices to increase straw production might not influence commercial straw yields. For example, foregoing the application of PGRs did not have a significant impact on straw yields but increased lodging risk (Townsend et al., 2017). That study recommended that growing wheat to maximise grain yield would follow through to higher straw yields; it is likely that farmers are already undertaking this approach meaning that there are limited options for increasing straw yield without compromising grain yield. Interestingly, one respondent stated that they already manage their crop for higher straw yields; this suggests that farmers might be finding that actions they take can lead to higher straw yields though whether this is economical is not clear.

Glithero et al. (2013a) found that respondents would prefer to commit to contracts for straw by total area rather than total weight this would not provide a direct incentive to increase straw yield per unit area. Selling by area facilitates planning decisions as well as reducing uncertainty for farmers as to how much of their crop they would need to bale; as highlighted above, the amount of rainfall has been observed to influence straw yields, introducing a further level of output uncertainty for farmers supplying a fixed tonnage of straw in comparison to a guaranteed area of straw.

Future straw supply

It has been shown in other studies that a significant proportion of farmers are unwilling to sell their straw (e.g. Glithero et al., 2013a). Altman et al. (2015) found straw supply for bioenergy was elastic to price so greater supply would be expected at higher prices but in this study,

even at a guaranteed price of £100 t^{-1}, 21% of farmers stated they were unwilling to sell any extra straw. In fact, 7% of respondents incorporated all their straw and were unwilling to sell any of it. ADAS (2008), in estimating straw supply, suggested only 2% of farmers would be unwilling to supply straw at £60 t^{-1}, which, given the results of this study suggests that ADAS's estimate is overly optimistic with respect to straw supply.

Littlewood et al. (2013) found that the price of bioethanol from wheat straw is very price sensitive to straw prices, so this suggests that at £100 t^{-1} straw would be prohibitively expensive as a biomass feedstock. Therefore, the findings from this current study strongly suggest that even with increased straw prices, a large proportion of straw will be unavailable for use in the biofuel sector and means that some current estimates of straw availability in England for biofuel production are too high (e.g. Scarlat et al., 2010).

There were no significant differences between regions, age groups, farm type or farm size in their willingness to supply straw at a price of £100 t^{-1}. Respondents who were unwilling to sell extra straw placed more importance on land stewardship, family objectives and quality of life as farming objectives; there was also a strong trend for placing importance on maintaining the environment. Land stewardship and family objectives suggest that those respondents have a long-term perspective for their farms and it is possible that they see the need for the long-term viability of the soil as placing a restriction on the amount of straw that can be sustainably removed. It is recognisable that short-term and long-term considerations about soil quality differed. One respondent noted that as a tenant farmer the long-term impact on the soil quality is of no concern to him/her so the respondent would bale as much as possible. Other respondents noted the long-term effects of straw incorporation and were incorporating straw for those long-term benefits. Glithero et al. (2013a) also found that concerns about soil compaction and health were barriers against supplying straw. The

importance of soil health is highlighted by a survey of Dutch arable farmers, which found 90.1% of respondents had a high or very high intention to increase soil organic matter (Hijbeek et al, 2018). There is currently much uncertainty about the impact of the removal of straw on soil health and quality. Some respondents in the current study stated that they had perceived crop yield benefits when moving back to incorporation after long-term straw removal. In a recent review of economic and environmental impacts of straw removal in the UK, Nicholson et al. (2014), show that straw removal was found to have variable impacts, both negative and positive, on soil characteristics and yields but in general impacts from straw removal were relatively small. The authors suggest that soil conditions, as well as agronomic considerations for the individual farm, are important in determining whether straw should be baled and removed or chopped and incorporated.

Some survey respondents were strongly opposed to the use of straw for biofuels. Many respondents who had livestock voiced concerns about potential increases in costs resulting from the use of straw for bioenergy, whilst respondents without livestock were also concerned about the impact on livestock farmers. Giannoccaro et al. (2017) found that farmers wanted a higher price for selling straw to a bioenergy market than to existing markets; although our questionnaire did not specify the straw was for bioenergy uses, from the description of the project that the survey was part of, it may have been assumed that this was the case. It is unclear if, once a bioenergy market is established, whether farmers' opinions about the supply of straw for bioenergy would change, and whether prices would equilibrate with other straw markets. This may need to be considered when assessing straw availability.

Survey design

In creating this postal survey, a balance had to be struck between maximising the return rate and maximising the quality and quantity of data returned by each respondent. Too many questions and the inclusion of questions about personal information (e.g. finances) can act as barriers to responses (Dillman et al., 2008); however, interpreting responses without a more complete context of the farm system can be challenging. For further studies utilising postal surveys we would recommend collecting more specific information on the farm system, including farm finances and details about the decision maker (e.g. on-farm vs off-farm income, average numbers of workers, family labour, education level, etc.). This could be done using broad categories to not discourage completion of the questionnaire. Even if this leads to fewer responses, by collecting this additional information, the data can be more thoroughly explored to provide greater insight.

Conclusions and Policy Implications

Projected bioenergy futures are predicated on the basis of a supply of biomass from waste, dedicated energy crops and agricultural residues such as cereal straw. An important consideration is the sustainability of the removal of straw on the soil (Searle & Bitnere, 2017) and there are estimates of straw supply that account for this (e.g. Searle & Malins, 2016); however, our study and others have shown that there are farmers who are unwilling to supply straw regardless of whether the straw can be removed sustainably. When these projections are presented without a consideration of farmer willingness to supply there is a risk that they may be interpreted incorrectly by policymakers, leading to bioenergy developments that are unsuited to the feedstock that is available. The results presented herein demonstrate the challenge facing an envisaged bioenergy sector reliant upon cereal straw supply. A substantial proportion of farmers, particularly in the East of England where large areas of

cereals are produced, are unwilling to change *from* their current practice of straw incorporation, *to* supplying straw for bioenergy purposes. These on-farm decisions are influenced by a range of factors with concerns about timeliness and negative soil impacts being the most commonly expressed. An unwillingness by some farmers to supply additional straw is arguably well-founded on the basis that maintaining and increasing soil organic matter is of greater importance to their own business sustainability, than the shorter term financial benefit from additional crop revenues. In addition, where farmers are willing to change crop management or harvesting practices in order to supply greater quantities of straw to the market, their preference is for area-based over tonnage-based contracts. Variation in straw availability between years due to weather conditions needs to be considered as in years of low straw supply, competition between a bioenergy market and existing straw markets could result in bioenergy plants operating under sub-optimal capacity or straw users having to source alternative resources, potentially increasing costs. These findings have important implications for energy and agricultural policy makers alongside the bioenergy processing sector. Energy policy makers must recognise the constraints the above results have identified with respect to biomass supply from cereal straw and modify downwards their expectations to which agricultural by-products such as straw can contribute to bioenergy production. Consequently, energy policy makers seeking to incentive supply should arguably target farmers who already have some willingness to supply biomass from cereal straw, while being cognisant of the farmer objective-based constraints that exist. In relation to the bioenergy processing sector, our findings suggest that innovative contract arrangements, and evidenced-based support to farmers in relation to the quantities of straw that need to be returned to land in order to build organic matter, need to be nested within their farmer engagement activities. It is argued here that energy policy makers and the bioenergy processing sectors must therefore align their messaging to farmers in order to achieve sustainable straw supply. The

main agri-environment policy challenge and opportunity in this space relates to the sustainability of soil health; achieving the appropriate balance of organic matter retention and removal is central to this. The direction of agricultural policy in England is aligned to this objective. While agricultural by-products will play a key role in sustainable bioenergy futures, it is argued here that this role may be more limited in scale, and more nuanced in nature, than previously identified. It is therefore of crucial importance that energy and agri-environmental policy makers align thinking, messaging and delivery within the complex policy space within which bioenergy from cereal straw is positioned.

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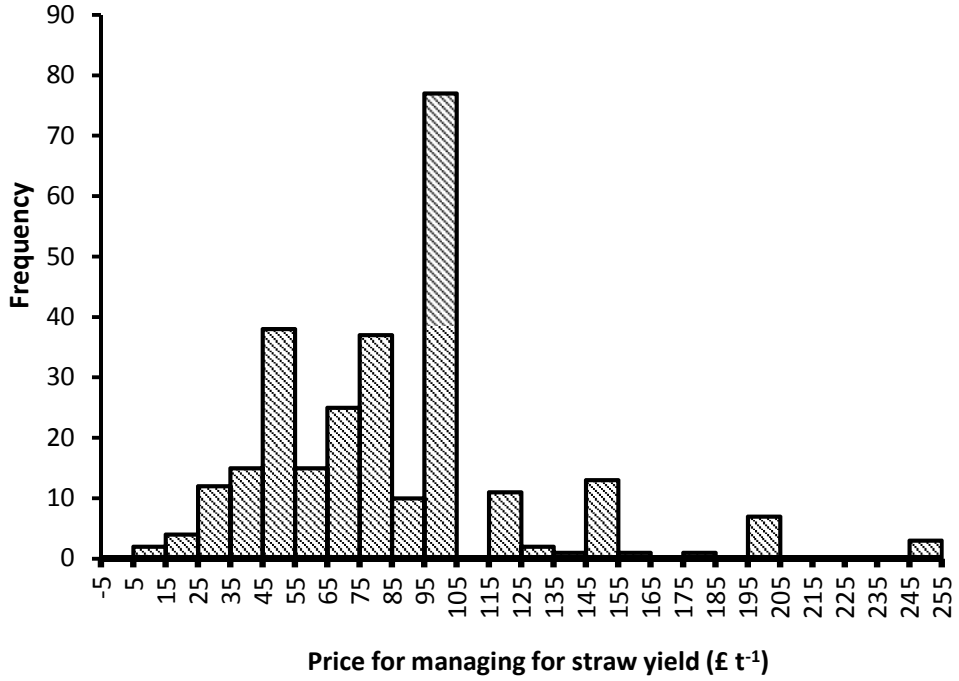
Figures

Figure 1: Price per tonne of straw that is required for growers to manage for straw yield

Figure 2: Choice of management practices for increasing straw yield given a price of £100 tonne^{-1} straw

Figure 1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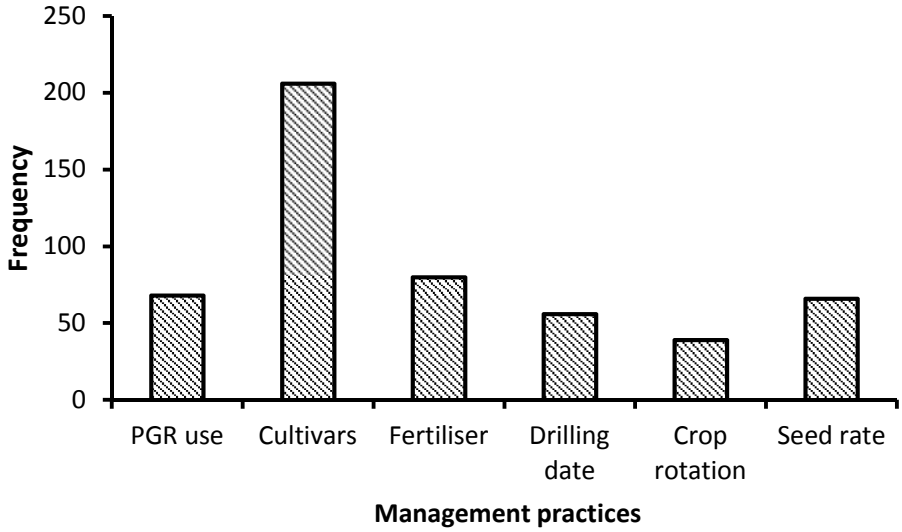
Price for managing for straw yield (£ t-1)

Figure 2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Seed rate
Management practices

Table headings

Table 1: Straw use per region, age, farm type and farm size groupings given as hectares with percentage of each group in parentheses. N.B. percentages may not add up to 1 due to rounding.

Table 2: Observed frequency of respondents for each straw incorporation category for groups (region, farm size, farmer age, farm type) with expected frequencies in parentheses. Chi-square (χ) and *P* values with degrees of freedom (df) in parentheses).

Table 3: Observed frequency of respondents willing and unwilling to supply additional straw on farms with available straw for each grouping (region, farm size, farmer age, and farm type) with expected frequency given in parentheses. Chi-square (χ) and *P* values with degrees of freedom (df) in parentheses).

Table 4: Observed and expected (in parentheses) frequencies of those willing to sell extra straw, those who already utilise all their straw, and those unwilling to sell more straw compared to attitudes towards farming objectives. Chi-square (χ) and *P* values with degrees of freedom (df) in parentheses).

Table 5: Results from an ANOVA of the price for managing for straw yield for each group (region, farm size, farmer age, and farm type). F, standard error of the differences of the means (SED) and *P* values with degrees of freedom (df) in parentheses.

Table 6: Observed and expected (in parentheses) frequencies of willingness to utilise management practices to increase straw yield for each group (region, farm size, farmer age, and farm type). Chi-square (χ) and *P* values with degrees of freedom (df) in parentheses).

Table 1 – Straw use

	Sold	Chopped	On-farm	Other	Total
Region					
East Midlands	8,276 (34%)	11,860 (49%)	3,120 (13%)	976 (4%)	24,232
East of England	10,688 (28%)	25,224 (65%)	1,906 (5%)	1,078 (3%)	38,896
North East	1,594 (62%)	555 (22%)	411 (16%)	11 (<1%)	2,571
South East	4,918 (26%)	6,698 (49%)	1,767 (1%)	186 (1%)	13,569
Yorkshire	4,360 (39%)	4,931 (44%)	1,122 (10%)	799 (7%)	11,212
Other	3,062 (41%)	4,207 (56%)	209 (3%)	0 (0%)	7,478
Farm type					
Cereal	23,783 (33%)	43,304 (60%)	3,887 (5%)	1,592 (2%)	72,565
General	8,492 (39%)	9,485 (43%)	2,657 (12%)	1,387 (6%)	22,020
Other	624 (18%)	686 (20%)	1,993 (59%)	71 (2%)	3,373
Farmer age					
25-34	1,079 (40%)	1,192 (44%)	444 (16%)	0 (0%)	2,715
35-44	3,881.5 (20%)	13,885 (73%)	1,029.5 (5%)	185 (1%)	18,981
45-54	11,429 (39%)	13,106 (45%)	3,558 (12%)	914 (3%)	29,007
55-64	9,825 (35%)	13,941 (50%)	2,629 (9%)	1,700 (6%)	28,095
65-74	4,917 (35%)	8,204 (59%)	701 (5%)	142 (1%)	13,964
>=75	1,274 (31%)	2,710 (65%)	84 (2%)	81 (2%)	4,149
Farm size					
<50	251 (58%)	144 (33%)	41 (9%)	0 (0%)	436
50-99	1,058 (50%)	722 (34%)	202 (9%)	147 (7%)	2,129
100-199	3,801 (45%)	3,272 (39%)	830 (10%)	528 (6%)	8,431
200-299	4,567 (51%	2,975 (33%)	1,088 (12%)	258 (3%)	8,888
300-499	5,299 (34%)	8,267 (52%)	1,762 (11%)	488 (3%)	15,816
500-999	6,759 (32%)	11,159 (52%)	2,506 (12%)	852 (4%)	21,276
>=1,000	11,162 (27%)	26,936 (66%)	2,107 (5%)	777 (2%)	40,982
Total	32,897	53,475	8,536	3,050	97,958

Table 2 – Straw incorporation

	Chopped and incorporated					
	0%	1-50%	51-99%	100%	χ (df)	P
Region						
East Midlands	44 (44.94)	19 (21.68)	26 (22.35)	23 (23.02)	54.01 (12)	<0.001
East of England	51 (72.22)	30 (34.82)	42 (35.93)	57 (37.02)		
North East	10 (7.22)	7 (3.48)	0 (3.59)	1 (3.70)		
South East	36 (35.71)	19 (17.23)	17 (17.76)	17 (18.30)		
Yorkshire	58 (38.92)	21 (18.77)	14 (19.36)	4 (19.95)		
Farm type						
Cereal	133 (146.33)	68 (70.35)	77 (73.87)	85 (72.46)	29.63 (6)	<0.001
General	46 (46.76)	28 (22.48)	25 (23.60)	17 (23.16)		
Other	29 (14.91)	4 (7.17)	3 (7.53)	1 (7.39)		
Farmer age						
25-44	15 (26.69)	14 (12.76)	22 (13.41)	15 (13.15)	37.64 (9)	<0.001
45-54	76 (62.67)	23 (29.96)	37 (31.49)	19 (30.88)		
55-64	60 (69.14)	44 (33.05)	32 (34.74)	35 (34.07)		
65+	54 (46.50)	17 (22.23)	12 (23.36)	32 (22.91)		
Farm size						
<50	14 (9.27)	1 (4.46)	3 (4.68)	5 (4.59)	76.25 (18)	<0.001
50-99	33 (24.19)	10 (11.63)	6 (12.21)	11 (11.98)		
100-199	66 (51.60)	21 (24.81)	12 (26.05)	29 (25.55)		
200-299	43 (34.26)	16 (16.47)	12 (17.30)	14 (16.97)		
300-499	24 (36.68)	22 (17.64)	26 (18.52)	19 (18.16)		
500-999	22 (29.43)	16 (14.15)	19 (14.85)	16 (14.57)		
>=1,000	6 (22.57)	14 (10.85)	27 (11.40)	9 (11.18)		

Table 3 – Willingness to supply extra straw

	Willing	Unwilling	χ (df)	P
Region				
East Midlands	64 (55.07)	17 (25.93)	8.40 (4)	0.078
East of England	80 (85.66)	46 (40.34)		
North East	10 (8.16)	2 (3.84)		
South East	17 (16.01)	33 (33.99)		
Yorkshire	36 (40.11)	23 (18.89)		
Farm type				
Cereal	162 (161.90)	77 (77.10)	3.71(2)	0.156
General	56 (52.16)	21 (24.84)		
Other	13 (16.94)	12 (8.06)		
Farmer age				
25-34	7 (6.80)	3 (3.20)	3.30(5)	0.654
35-44	27 (27.87)	14 (13.13)		
45-54	73 (67.96)	27 (32.04)		
55-64	75 (77.48)	39 (36.52)		
65-74	39 (38.74)	18 (18.26)		
>=75	6 (8.16)	6 (3.84)		
Farm size				
<50	7 (6.77)	3 (3.23)	10.94 (6)	0.090
50-99	32 (27.10)	8 (12.90)		
100-199	42 (48.10)	29 (22.90)		
200-299	41 (38.61)	16 (18.39)		
300-499	39 (45.39)	28 (21.61)		
500-999	36 (35.90)	17 (17.10)		
>=1,000	34 (29.13)	9 (13.87)		

Table 4 – Attitudes and willingness to supply additional straw

	Willing	Unwilling	χ (df)	P		Willing	Unwilling	χ (df)	P
Land stewardship					Profit				
Neutral	51 (45.95)	17 (22.05)	9.15 (2)	0.010	Neutral	11 (9.45)	3 (4.55)	2.37 (2)	0.306
Important	118 (111.50)	47 (53.50)			Important	76 (81.64)	45 (39.36)		
V. Important	54 (65.55)	43 (31.45)			V. Important	137 (132.92)	60 (64.08)		
Yields					Quality of life				
Neutral	8 (7.42)	3 (3.58)	1.83 (2)	0.401	Neutral	19 (22.30)	14 (10.70)	8.14 (2)	0.017
Important	103 (97.82)	42 (47.18)			Important	114 (102.03)	37 (48.97)		
V. Important	115 (120.76)	64 (52.24)			V. Important	92 (100.68)	57 (48.32)		
Gross margins					Leisure				
Neutral	6 (4.74)	1 (2.26)	1.79 (2)	0.409	Neutral	69 (65.06)	27 (30.94)	1.06 (2)	0.589
Important	58 (61.57)	33 (29.43)			Important	104 (107.08)	54 (50.92)		
V. Important	162 (159.69)	74 (76.31)			V. Important	52 (52.86)	26 (25.14)		
Environment					Family				
Neutral	25 (23.58)	10 (11.42)	5.69 (2)	0.058	Neutral	66 (59.56)	22 (28.44)	7.01 (2)	0.030
Important	158 (150.90)	66 (73.10)			Important	84 (79.87)	34 (38.13)		
V. Important	42 (50.52)	33 (24.48)			V. Important	72 (82,57)	50 (39.43)		

Table 5 – Straw price required for management for additional straw yields

	No. of respondents	Mean price (£ tonne^{-1})	F (d.f.)	SED	P
Region					
East Midlands	64	79.84	0.52 (4, 253)	10.46	0.718
East of England	89	83.30			
North East	13	78.15			
South East	44	84.77			
Yorkshire	48	88.71			
Farm type					
Cereal	194	82.89	2.07 (2, 268)	9.73	0.129
General	62	83.98			
Other	15	102.67			
Farmer age					
25-44	34	101.80	3.58 (3, 263)	7.18	0.015
45-54	91	84.33			
55-64	89	80.01			
65+	53	78.54			
Farm size					
<50	11	76.36	0.49 (6, 264)	12.03	0.815
50-99	30	86.83			
100-199	60	78.78			
200-299	49	84.88			
300-499	47	89.19			
500-999	40	84.50			
>=1,000	34	86.03			

Table 6 – Willingness to manage for increased straw yields

	Unwilling	Willing	χ (df)	P
Region				
East Midlands	32 (35.04)	59 (55.96)	11.14 (4)	0.025
East of England	67 (53.90)	73 (86.10)		
North East	2 (6.16)	14 (9.84)		
South East	25 (28.11)	48 (44.89)		
Yorkshire	28 (30.80)	52 (49.20)		
Farm type				
Cereal	121 (115.11)	179 (184.89)	6.69 (5)	0.244
General	34 (35.30)	58 (56.70)		
Other	5 (9.59)	20 (15.41)		
Farmer age				
25-34	6 (4.21)	5 (6.79)	4.13 (2)	0.127
35-44	17 (16.47)	26 (26.53)		
45-54	49 (50.55)	83 (81.45)		
55-64	58 (55.91)	88 (90.09)		
65-74	19 (24.89)	46 (40.11)		
>=75	8 (4.98)	5 (8.02)		
Farm size				
<50	4 (5.37)	10 (8.63)	12.18 (6)	0.058
50-99	12 (19.57)	39 (31.43)		
100-199	30 (36.83)	66 (59.17)		
200-299	30 (28.01)	43 (44.99)		
300-499	36 (29.16)	40 (46.84)		
500-999	28 (23.41)	33 (37.59)		
>=1,000	20 (17.65)	26 (28.35)		

Supplementary material

Questionnaire

Today's date:

Question 1 – In which county is your farm?

Question 2 – Do you grow wheat? (If you answer NO then please return the survey without answering the remaining questions.) [Choice of YES or NO]

Question 3 – What is the size of the farm (including any land under contract farming agreements)? (Please answer in either hectares or acres)

Question 4 – What area of the following crops did you grow for the 2012 harvest? (Please answer in either hectares or acres:

	Hectares	Acres
Wheat intended for milling		
Wheat intended for animal feed		
Winter barley		
Spring barley		
Oats		
Maize		
Sugar beet		
Oilseed rape		
Potatoes		
Beans/peas		
Bioenergy crops		
Grass		
Other (*please say*)		
Other (*please say*)		

Question 5- What livestock have you had on your farm in 2012?

	Average number on farm in 2012
Sheep (ewes)	
Sheep (other than ewes – e.g. store lambs)	
Dairy cows	
Suckler cows	
Store cattle, calves or other breeding cattle	
Poultry (hens, turkeys, broilers, other poultry)	
Pigs (breeding sows)	
Pigs (weaners bought for finishing)	
Other (*please say*)	
Other (*please say*)	

Question 6 – On average how frequently do you change the wheat varieties that you grow?

Every year	
Every 2-3 years	
Every 4-5 years	
Every 6+ years	

Question 7 – On average how many wheat varieties do you grow at a time?

1	
2	
3	
4	
5+	

Question 8 – How was the wheat straw from the 2012 harvest used? (Please answer in hectares or acres)

		Hectares	Acres
Sold as baled	for livestock		
	for industry, e.g. building materials		
	for bioenergy		
	third party unknown market		
Sold in swath	for livestock		
	for industry, e.g. building materials		
	for bioenergy		
	third party unknown market		
Chopped and incorporated			
Baled for on farm use			
Other (*please say*)			

Question 9 – How important do you consider the following characteristics when choosing wheat varieties? *Please rate the importance of each characteristic.*

	Very important	Important	Neutral	Unimportant	Very unimportant
Potential gross margins					
Grain yield					
Resistance to lodging					
Seed cost and availability					
Resistance to disease					
Crop timing constraints (e.g. sowing/harvest dates)					
Customer preferences and contractual requirements					
Other (*please say*)					
Other (*please say*)					

Question 10 - When selecting which <u>wheat varieties</u> to grow, how important are the following sources of information? *Please rate the importance of each source*

	Very important	Important	Neutral	Unimportant	Very unimportant
HGCA recommended lists					
Own knowledge and experience					
Agronomist					
Word-of-mouth (e.g. neighbouring farmers)					
Customer preference and contractual requirements					
Other (*please say*)					
Other (*please say*)					

Question 11- At what price for <u>wheat straw</u> (£ per tonne baled at the farm gate) would you start to manage your wheat for straw yields as well as grain yields?

Question 12 – Would you increase the amount of <u>wheat straw</u> you sell if you were offered one of the following?

- a guaranteed price of £100 per tonne of <u>baled straw at the farm gate</u>
- a guaranteed price of £162 for <u>1 hectare</u> (£65 for 1 acre) of wheat straw in swath

YES	
NO	
I already sell all my straw	

Question 13 – Would you use any of the following management practices to increase <u>wheat straw</u> yields if you were offered one of the following?

- a guaranteed price of £100 per tonne of <u>baled straw at the farm gate</u>
- a guaranteed price of £162 for <u>1 hectare</u> (£65 for 1 acre) of wheat straw in swath

Please tick the relevant boxes and enter any additional management practices

Reduce plant growth regulator (PGR) use	
Select wheat varieties with higher straw yields	
Change fertiliser practices	
Drill earlier	
Change crop rotation	
Increase seed rate	
Other (*please say*)	
Other (*please say*)	

Question 14 – How important are the following objectives for your farm?

	Very important	**Important**	**Neutral**	**Unimportant**	**Very unimportant**
Land stewardship					
Maximising yields					
Maximising gross margins					
Maintaining the environment					
Profit maximisation					
Quality of life					
Leisure and work balance					
Family objectives and succession					

Question 15 – Have you had any diversification enterprises in 2012? *For example: agricultural contracting, processing or retailing farm produce, letting cottages, bed and breakfast, and livery. Please answer YES or NO. If you answer YES, please briefly mention what diversification enterprise(s) you have had.*

YES	
NO	

Question 16 – How long have you been the principal manager of the farm?

Question 17 – What is your age?

Less than 25	
25-34	
35-44	
45-54	
55-64	
65-74	
75+	

This is the end of the survey. A box is provided below if you would like to give any additional comments:

[Comments box]

Prize draw

If you would like to be entered into the prize draw, please supply your postal address or email address in the box below.