Potential for Second Generation Biofuel Feedstock from English Arable Farms

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Abstract[1]

Meeting the EU renewable fuel targets for 2020 will require a large increase in bioenergy feedstocks. To date, first generation biofuels have been the major response to meeting these targets. However, second generation biofuels from dedicated energy crops (e.g. miscanthus) or crop residues (e.g. straw) offer potential. Based on an on-farm survey of Farm Business Survey arable farmers in England and aggregated to national levels, we estimate that 5.27 Mt of cereal straw is produced annually on these farm types, of which farmers indicated that they would be willing to sell 2.5 Mt for bioenergy purposes, provided appropriate contractual conditions meet their needs. However, only 555Kt-840Kt would be obtained from straw currently incorporated into the soil. Timeliness of crop operations and benefits to soil were cited as key reasons for incorporating straw. A 'good price' represents the key incentive to encourage straw baling. With respect to dedicated energy crops, 81.6% (87.7%) would not consider growing miscanthus (SRC), while respectively, 17.2% (11.9%) would consider growing and 1.2% (0.4%) were currently growing these crops. Assuming 9.29% (average percentage of arable land set-aside between 1996-2005) of their utilised agricultural area to these crops, 89,900 ha (50,700 ha) of miscanthus (SRC) would be grown on English arable farms. Land quality issues, profitability and committing land for a long period of time were cited as both negative and positive reasons for farmer decisions about their level of willingness to grow these crops. Food and fuel policies must increasingly be integrated in order to meet societal goals without generating unintended consequences.

1. Introduction

Concerns over energy security and the environmental impacts of fossil fuel energy use have resulted in the implementation of renewable bioenergy policies (Mitchell and Connor, 2004; Thornley and Cooper, 2008; Slade *et al*., 2009). Both the EU and USA have legislation in place to derive a proportion of energy from 'renewables' (EU, Directive 2009/28/EU; USA, Public Law 110-140 (2007)). First generation bioenergy represents the major technology (Sims *et al*., 2008; Environment Audit Committee, 2008) thus far being utilised to meet these legislative requirements. However, concern

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[1] This conference paper draws upon three forthcoming peer-reviewed articles to which readers are directed:
Glithero, N., Ramsden, S.J. and Wilson, P. (2013). Barriers and Incentives for cereal straw based bioethanol: a farm business perspective, *Energy Policy* (in press). 10.1016/j.enpol.2013.03.003
Glithero, N., Wilson, P. and Ramsden, S.J. (2013). Straw Use and Availability for Second Generation Biofuels in England, *Biomass and Bioenergy* (in press). 10.1016/j.biombioe.2013.02.033
Glithero, N., Wilson, P. and Ramsden, S.J. (2013). Prospects for arable farm uptake of Short Rotation Coppice willow and miscanthus in England, *Applied Energy* (in press). http://dx.doi.org/10.1016/j.apenergy.2013.02.032

over food production competition exists, which is especially relevant given recent increased food scarcity and prices (Williams, 2008; Cassman and Liska, 2007; Zhang *et al*., 2010; Pimentel *et al.*, 2008). Second generation technologies draw upon lignocellulosic feedstocks (e.g. miscanthus, cereal straw) and within the UK a major research programme on second generation fuels has resulted from the Biotechnology & Biological Sciences Research Council (BBSRC) establishment of 'BSBEC', the BBSRC Sustainable BioEnergy Centre (Anon, 2012). Work within the Centre includes research into the lignocellulosic conversion of cereal straw and dedicated energy crops into bioethanol. Glithero *et al*. (2012) divide second generation biofuel into dedicated energy crop second generation biofuel (DESGB) and co-product second generation biofuel (CPSGB); the latter utilises co-products from 'food' crops (e.g. cereal straw; corn stover). The dedicated energy crops (DEC) of miscanthus and short rotation coppice (SRC) are perennial crops and are thus not grown in the normal rotational cropping patterns found on UK arable farms. SRC willow can be first harvested three to four years after plantation and thereafter every three years (Finch *et al.*, 2009) with a lifespan range between 22 and 30 years (Ericsson *et al*., 2009; Karp and Shield, 2008). Miscanthus is generally propagated by planting rhizome sections and is harvested towards the end of its second year after planting, and annually thereafter with an approximate 15-20 year lifespan (Finch *et al*., 2009; Karp and Shield, 2008: Finch *et al.*, 2009; Nix, 2012). DECs have been argued to offer the potential for efficient energy production per hectare (Powlson *et al.*, 2005); however, farmer uptake of these crops is anticipated to remain low in the foreseeable future (Sherrington *et al*., 2008; Sherrington and Moran, 2010). Contrasting with the small area of DECs grown (3,000ha of SRC; 8,000ha of miscanthus in England [Anon, 2011]), large areas of cereal crops are grown in the UK, largely in the Eastern parts of England. However, data on the production and utilisation of cereal straw is generally lacking, albeit that previous authors have noted that 'surplus straw' may provide a potential lignocellulosic feedstock supply (Copeland and Turley, 2008). Moreover, using 'surplus' straw would arguably avoid food-fuel conflicts and concerns over land use change (Londo *et al.*, 2010; Naik *et al*., 2010; Nigam and Singh, 2011; Williams, 2008). Despite this potential, sustainability concerns from the use of cereal straw as a feedstock exist (Thornley *et al*., 2009; Cherubinia and Ulgiatib, 2010; Lal, 2008). The UK has implemented a range of policies to support renewable energy (Mitchell and Connor, 2004) which at the farm-level are restricted to support packages for DECs. With respect to the availability of cereal straw or DECs, understanding farmer decision making with respect to their cropping and marketing decisions is a necessary condition of commercial success; these factors have hitherto largely been under researched. Furthermore, transportation costs of dedicated energy crops and cereal straw will account for a large proportion of the delivered value of feedstocks. Hence, understanding supply chain logistics in additional to farmer attitudes and decision making will be a central aspects of commercial practicality. Aspects of farmer decision making cannot be easily elicited from aggregate production data or economic modelling alone and hence require investigation via primary data collection methodologies.

The objectives of this paper therefore are to: (i) describe the scope and methodology of an on-farm survey seeking to obtain data on farmer decision making and attitudes towards cropping practices, (ii) combine these data with information on cropping, location, and associated factors from the English Farm Business Survey (FBS) (iii) aggregate survey data to provide estimates for regional and national (English) straw supplies and use and dedicated energy crop potential, and iv) investigate farmer preferences for contractual aspects of cereal straw supply. The survey scope, structure, sampling strategies and data analysis details are given in section 2. Results are presented in section

3, sub-divided to relevant sub-sections. The discussion and conclusion in section 4 places the results in context of previous research findings and policy relevance.

2. Methods

A survey approach was taken to obtain data on straw use and volumes, contract preferences and attitudes towards dedicated energy crops on arable farm types (Cereal, General Cropping, Mixed) in England. Firstly, the survey questionnaire contained a variety of questions on straw use, straw volumes baled, crop cultivations, cereal variety choice, straw incorporation into the soil and contract implications of bioethanol production; 249 returns were available for analysis from these questions. Secondly, questions relating to the price at which farmers would sell cereal straw, the amounts they would be willing to supply, the length of time they would supply straw for, and their price and straw supply quantity preferences for inclusion in an industry supply contract were included, together with information on the potential barriers to the removal of straw and incentives needed to gain this co-product from farmers; 240 returns within this section were available for analysis. Questions relating to farmer's willingness to grow SRC and miscanthus, and the importance of different factors in their decision on growing DECs were also captured, generating 244 completed farm returns for analysis.

Following Oppenheim (2011) appropriate questionnaire design techniques (funnelling of questions and including a combination of closed, rating scale and open questions), were adopted during the design phase. The questions drew upon expert knowledge of the sector and 'knowledge transfer' events with arable farmers (e.g. UK *Cereals*[2] event, on-farm farmer-discussions) to inform both questions of interest and detailed options for possible answers. On-farm survey data collection was obtained by using experienced Farm Business Survey (FBS) Researchers Officers (ROs) from Rural Business Research (RBR) units in England as part of the annual FBS research programme. Prior to full implementation (February 2011 to October 2011), the questionnaire was piloted by RBR ROs during December 2010 to February 2011 and feedback from both farmers and RBR ROs was incorporated into the questionnaire, leading to questions being removed, or reworded for greater clarity, to allow accurate responses to be obtained. The final questionnaire was designed to be linked to production and business data from the FBS. Where straw was baled the number of bales was recorded according to the type of bale: large and small Hesston, large-round, small-square and other. These data related to the 2010 crop harvest straw use. Combining questionnaire data with the FBS data on cropping areas for 2010 harvest, allows estimates of straw volumes and uses to be calculated alongside potential for dedicated energy crop areas. The FBS research programme sample is based upon population data from Defra's annual June Survey returns of the structure of the industry to ensure that the FBS is stratified to reflect population practice by farm type by Government Office Region (GOR). The survey was carried out on 46% of the FBS co-operators within the main arable farm types within the FBS: Cereals, General Cropping, Mixed. Straw use data was collected from questions pertaining to straw use by percentage area. Straw yields were based on farmers' estimates of number of bales and standard figures for bale weights; per farm straw production was calculated from the estimated straw yields multiplied by crop areas from the FBS[3]. Aggregation from sample to national results was based upon a farm weighting procedure following advice from Defra

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[2] The UK Cereals event describes itself as 'the leading technical event for the UK arable industry' with approximately 26900 visitors annually.

[3] See Glithero *et al.* (2013a). Details available from the authors upon request.

statisticians[4]. Where qualitative data was collected Chi-squared tests have been performed in order test for location (GOR and EU regions), farm type and farm size effects; where expected cell counts of less than five occurred, categories were combined to ensure that the assumptions of the Chi-squared test were not violated. Estimates of straw availability to the market for bioenergy purposes have been calculated on the assumption that, for farms which currently chop and incorporate straw, the straw that would be made available for bioenergy purposes would, in the first instance, be derived from that straw which is currently incorporated, and where the stated volume to be sold exceeds that currently incorporated, it is assumed that the straw supply would displace that currently baled and sold or used on farm. With respect to estimating production of dedicated energy crops, it has been assumed that 9.29% (average arable land set aside 1996-2005) of the UAA on a farm is converted to these crops in those instances where a farmer was willing to grow, or is already growing these crops.

3. Results

3.1. Harvested Grain to Straw Yield Relationships and England yields

From the 249 useable arable farm observations, 227 farms grew wheat, 162 barley and 140 oilseed rape. Combining the 2010 FBS data with the survey information allows average harvestable straw yields to be calculated and compared to grain yields. No clear relationship between harvested grain to straw yields for wheat or oilseed rape across England was observed (Spearman's rank correlation coefficient (SRCC) of 0.126 and -0.271 respectively; not statistically significant), however for barley the SRCC is 0.410 ($p<0.001$) showing a weak relationship; see Figure 1. English harvestable straw yields for wheat, barley and oilseed rape from arable farms are 2.53t ha^{-1}, 2.26t ha^{-1} and 1.65t ha^{-1} respectively (median values)[5]. Table 1 reports straw practices on English arable farms, indicating the distinct differences between GORs, for example in the East of England 51% of the straw from the barley crop area is incorporated into the soil, accounting for 98% of all the incorporated English barley straw area; the East of England also incorporated 64% of wheat straw by area, equating to 53% of the total English wheat straw area incorporated. In aggregate, 36%, 18% and 87% of the straw areas for wheat, barley and oilseed rape on arable farm types respectively are incorporated.

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[4] Steve Langton; Defra York.

[5] The median values for wheat and barley have 95% confidence intervals of (2.31, 3.06) and (2.07, 2.67) respectively. The median values reported are more relevant than means due to the non-normal distribution of the straw yield data for these crops (wheat and barley), tested using the Shapiro-Wilk test for normality (wheat $p = 0.003$ ($n=119$), barley $p <0.001$ ($n=105$) both of which are significant indicating that the null hypothesis that the distribution is normal is rejected). Data observations for oilseed rape were limited, hence it was deemed inappropriate to test for normality for this crop.

3.2. Regional Straw Yields

Regional straw yields and practices are highlighted in Table 2, showing considerable variation across England. The total tonnage of wheat and barley straw used is larger than that incorporated in all GORs, excepting the East of England. The majority of the barley straw is used in some form, while most oilseed rape straw was incorporated leading to insufficient data observations on baled oilseed rape straw to calculate regional straw yields. Overall, our estimates suggest that 1.45 million tonnes of harvestable cereal straw is currently incorporated from Cereal, General Cropping and Mixed farms in England, albeit that considerable variation in harvestable straw yields is estimated, arguably indicating that there is scope for improvement in retrieved straw yields, particularly in the East of England. Based upon oilseed rape yield data, there is at least 700,000 tonnes of oilseed rape straw in England, from the three arable farm types, currently incorporated into the soil. Note from Table 2 that although the East of England grows the largest area of wheat and barley, it is the East Midlands region that is estimated to produce the largest tonnage of cereal straw; the East of England contains the greatest tonnage of incorporated cereal straw in England.

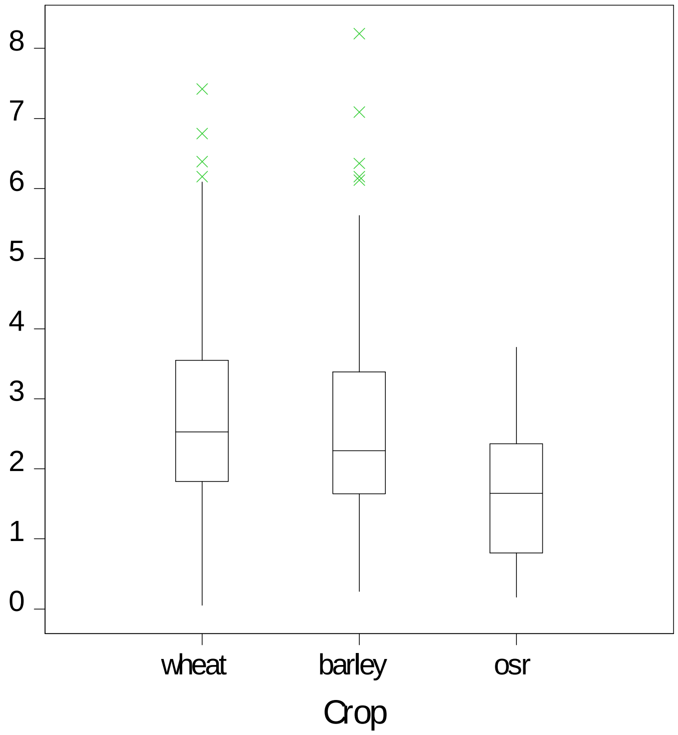

Figure 1: Wheat, barley and oilseed rape (osr) straw yield distribution (wheat n=119, barley n=105, osr n=9). Source: Glithero *et al*. (2013a)

Table 1: Crop Areas (hectares) on Arable Farm Types by GOR and Straw Use

GOR (GOR Ref number)	Crop	chopped incorporated	baled for on-farm use livestock	baled on farm use other	sold baled agricultural use	sold baled industry use	sold baled other	sold in swath
North East (1)	Wheat	9,114	23,181	0	18,075	0	0	11,651
	Barley	0	16,310	0	5,001	0	0	10,822
	Oilseed rape	17,930	2,253	0	3,970	0	0	483
North West (2)	Wheat	0	412	682	6,464	0	869	15,639
	Barley	297	6,018	0	6,640	0	2,827	2,546
	Oilseed rape	4,012	0	0	0	0	0	290
Yorkshire & Humber (3)	Wheat	39,563	45,962	20,948	46,627	6,113	1,087	59,983
	Barley	0	41,452	771	28,263	0	7,386	12,385
	Oilseed rape	55,223	977	1,527	0	0	2,237	21,757
East Midlands (4)	Wheat	120,161	68,304	8,832	28,226	0	10,763	103,773
	Barley	706	19,618	0	15,046	0	1,651	22,671
	Oilseed rape	141,465	3,382	0	0	0	0	1,992
West Midlands (5)	Wheat	39,354	29,213	546	10,073	0	0	68,038
	Barley	0	10,389	0	5,777	0	609	18,321
	Oilseed rape	45,183	760	0	0	0	1,005	0
East of England (6)	Wheat	311,424	34,254	4,951	51,950	0	2,002	78,314
	Barley	60,737	23,469	353	10,333	0	6,011	17,572
	Oilseed rape	131,871	0	0	2,963	0	0	2,314
South East (8)	Wheat	64,285	60,246	0	52,205	1,858	7,888	35,725
	Barley	0	14,518	0	27,075	0	3,443	12,216
	Oilseed rape	66,621	9,685	0	4,337	0	0	0
South West (9)	Wheat	0	36,532	1,341	37,249	0	0	61,801
	Barley	0	23,336	0	14,858	0	2,480	29,938
	Oilseed rape	34,814	3,515	0	7,896	0	392	3,109
England	Wheat	583,901	298,104	37,300	250,869	7,971	22,609	434,924
	Barley	61,740	155,110	1,124	112,993	0	24,407	126,471
	Oilseed rape	497,119	20,572	1,527	19,166	0	3,634	29,945

Source: Glithero *et al*. (2013a)

Table 2: Straw Yields, Uses and Potential on Arable Farm Types

Crop	GOR	Area in GOR	Straw Yield (t/ha)	Potential Total Yield (t)	Yield Used (t)	Yield Incorporated (t)	Percentage Used	Percentage Incorporated
Wheat	1	62,021	2.52	156,114	133,172	22,941	85.30	14.70
	2	24,066	2.21	53,093	53,093	0	100.00	0.00
	3	220,285	2.76	606,894	497,895	108,999	82.04	17.96
	4	340,059	3.26	1,108,195	716,611	391,584	64.66	35.34
	5	147,223	1.88	277,353	203,215	74,139	73.27	26.73
	6	482,895	1.66	800,943	284,406	516,537	35.51	64.49
	8	222,206	3.34	741,744	527,155	214,589	71.07	28.93
	9	136,923	2.23	305,467	305,467	0	100.00	0.00
	Total	1,635,678	2.48	4,049,803	2,721,014	1,328,789	67.19	32.81
Barley	1	32,132	2.38	76,475	76,475	0	100.00	0.00
	2	18,328	2.00	36,647	36,053	594	98.38	1.62
	3	90,258	3.04	274,486	274,486	0	100.00	0.00
	4	59,692	3.58	213,753	211,224	2,530	98.82	1.18
	5	35,096	1.81	63,449	63,449	0	100.00	0.00
	6	118,475	1.95	230,685	112,422	118,264	48.73	51.27
	8	57,252	2.92	167,090	167,090	0	100.00	0.00
	9	70,611	2.25	158,641	158,641	0	100.00	0.00
	Total	481,845	2.53	1,221,228	1,099,840	121,387	90.06	9.94
Cereal Total		2,117,523		5,271,031	3,820,855	1,450,176	72.49	27.51
Oilseed rape	1	24,636	1.49	36,593	9,961	26,632	27.22	72.78
	2	4,303	1.49	6,391	431	5,960	6.75	93.25
	3	81,722	1.49	121,384	39,359	82,026	32.42	67.58
	4	146,839	1.49	218,105	7,982	210,123	3.66	96.34
	5	46,948	1.49	69,734	2,622	67,112	3.76	96.24
	6	137,148	1.49	203,711	7,839	195,873	3.85	96.15
	8	80,643	1.49	119,782	20,827	98,955	17.39	82.61
	9	49,726	1.49	73,859	22,149	51,710	29.99	70.01
	Total	571,964	1.49	849,560	111,169	738,390	13.09	86.91

Source: Glithero *et al*. (2013a)

3.3. Contract Volumes, Length of Contract and Supply and Pricing

The results above do not take into account farmer preferences for their use of straw under a potential bioenergy feedstock market, nor consider the contractual implications of such a market. From a variety of possible contract options, the most popular contract responses (Figure 2) were recorded as supplying a fixed area of straw (42% of farmers), for a fixed stated farm-gate price (34% of farmers, Figure 3). No significant impact of farm type, size and region was observed for contract price options; however, there is a significant impact of farm size and EU region on the preference for quantity options within contracts[6]. Approximately one third of Cereal (35%) and General Cropping (37%) farmers stated that they would supply a fixed area of straw; however, approximately one fifth (22%) of Mixed Farm farmers would find this option acceptable.

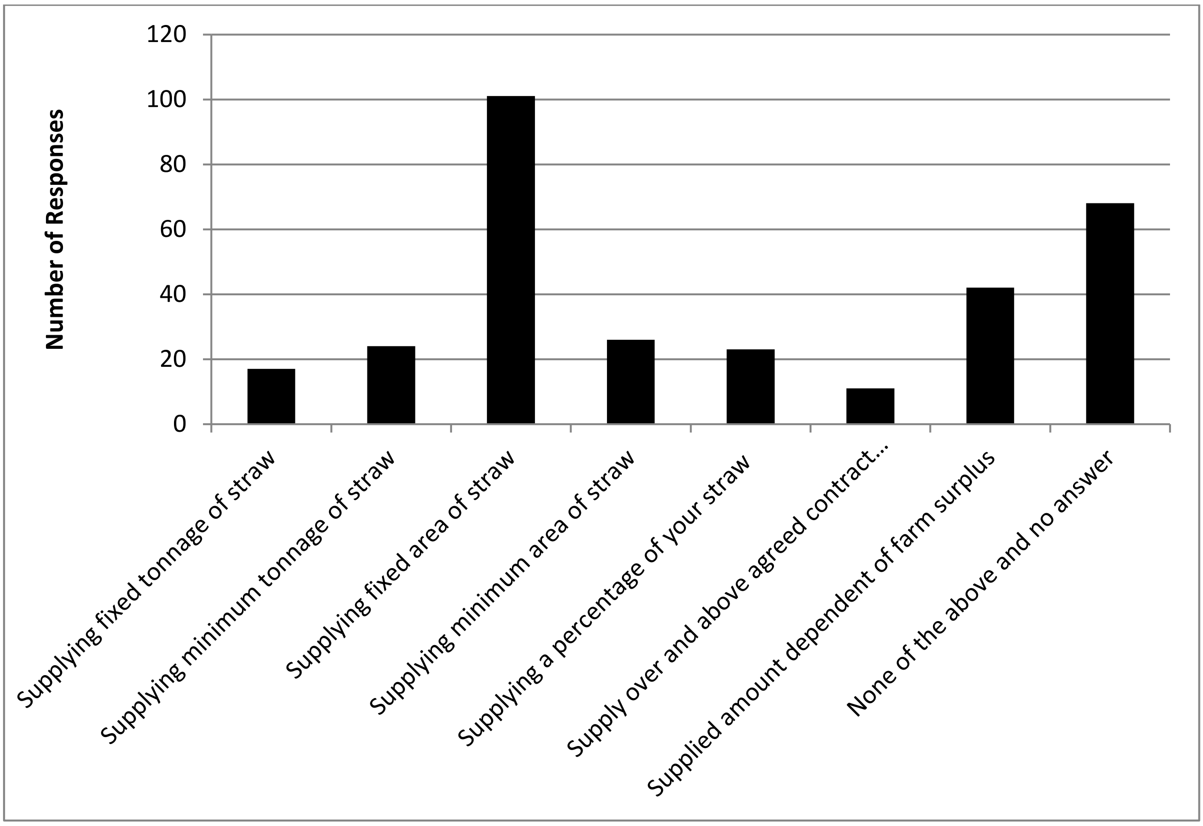

Figure 2: Quantity supply contract option preferences. Source: Glithero *et al*. (2013c)

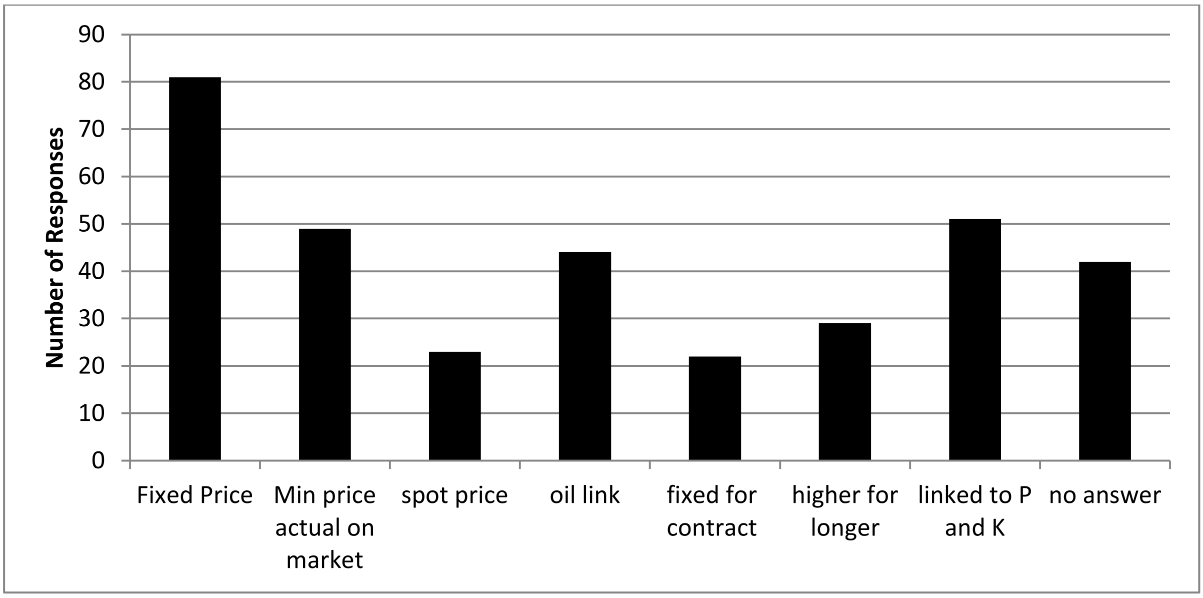

Figure 3: Price supply contract option preferences. Source: Glithero *et al*. (2013c)

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[6] Chi-squared test: these data were analysed with respect to farm type (Cereal, General Cropping and Mixed), farm size (Small, Medium and Large) and EU region (North England, West England and East England) to test the hypothesis of no influence of farm type (price, p=0.31; quantity, p=0.41), farm size (price, p=0.37; quantity, p=0.022) and EU region (price, p=0.41; quantity, p=0.002) on price and quantity responses.

The most popular contract lengths were three years (23%), one year (22%) and 'none' (20%) and the most popular number of consecutive years of supply were none (24%) one year (18%) and three years (17%). The majority (71%) of farmers cited the same response for both the consecutive number of years of supply and maximum contract length. Although contract lengths of three years or less were most popular, five year contracts with five years of consecutive supply was also cited by 10%, and 14% would supply for 15 consecutive years, albeit that the majority of these respondents would not wish to agree to a contract length of 15 years duration.

The most frequently cited minimum price at which farmers would supply straw was estimated at £50t^{-1} selected by 24% of all respondents irrespective of whether they would actually sell straw. Additionally, this was the modal response from the 157 respondents that would be willing to sell their wheat straw. The variability in the farm-gate price response data can be observed when linked to GORs (Figure 4); there appears to be no East-West differentiation given that the highest mean prices were observed in the East Midlands and the South West.

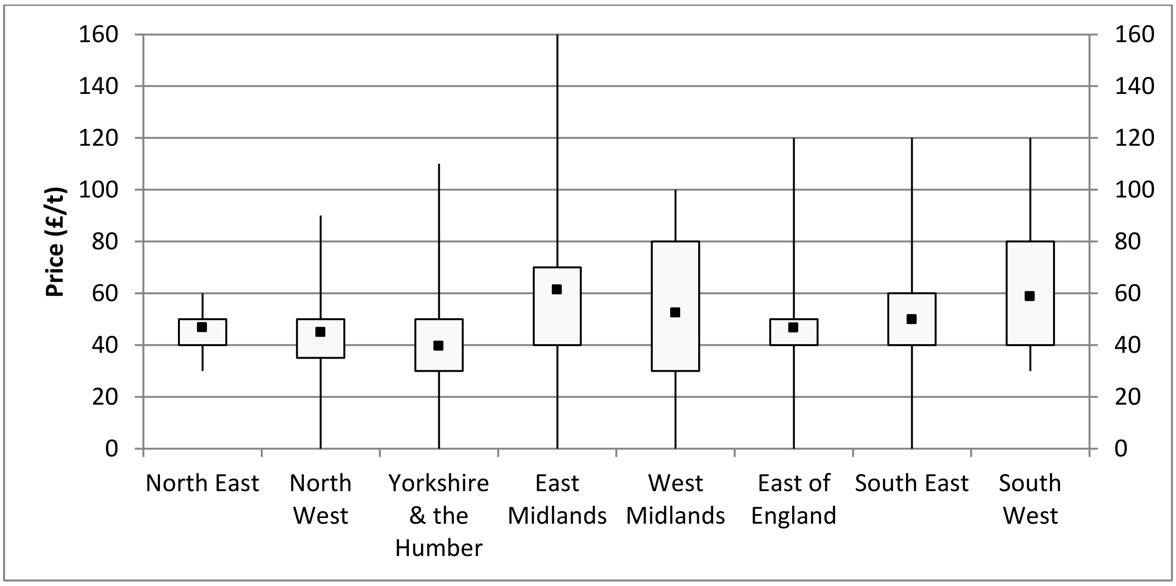

Figure 4: Minimum price for wheat straw by Government Office Region. The boxes represent the 25% and 75% quartiles with the whiskers showing the full extent of the data. Source: Glithero *et al*. (2013c)

3.4. Reasons for not Baling Straw and Incentives to Encourage Baling

Reasons for not baling straw were obtained from those farmers incorporating some or all of their cereal straw. In the case of wheat and barley (Figure 5), 28% of all farmers stated that timeliness of operations (i.e. delays in establishment of the next crop) was the main reason for not baling (including selling in swath) with 24% stating perceived benefits of incorporation (e.g. soil structure/nutrients). Farmers were also asked what single factor would most encourage them to bale their straw (Figure 6); a 'good price' for straw was cited by 26% of farmers representing the modal response.

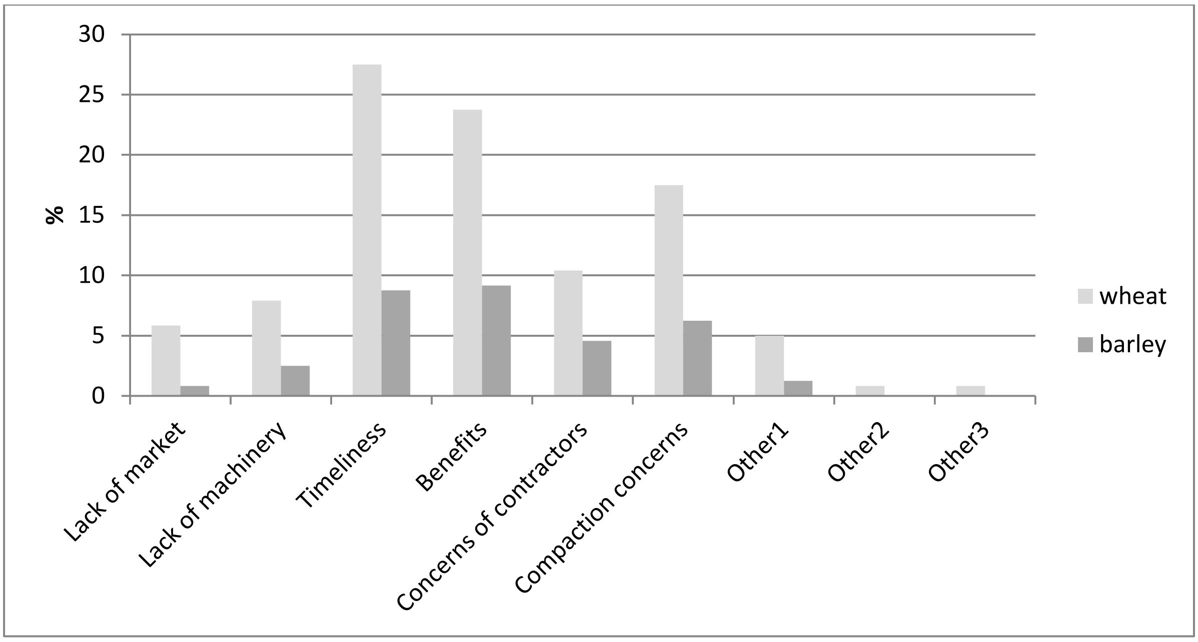

Figure 5: Reasons for not baling straw. Source: Glithero *et al*. (2013c)

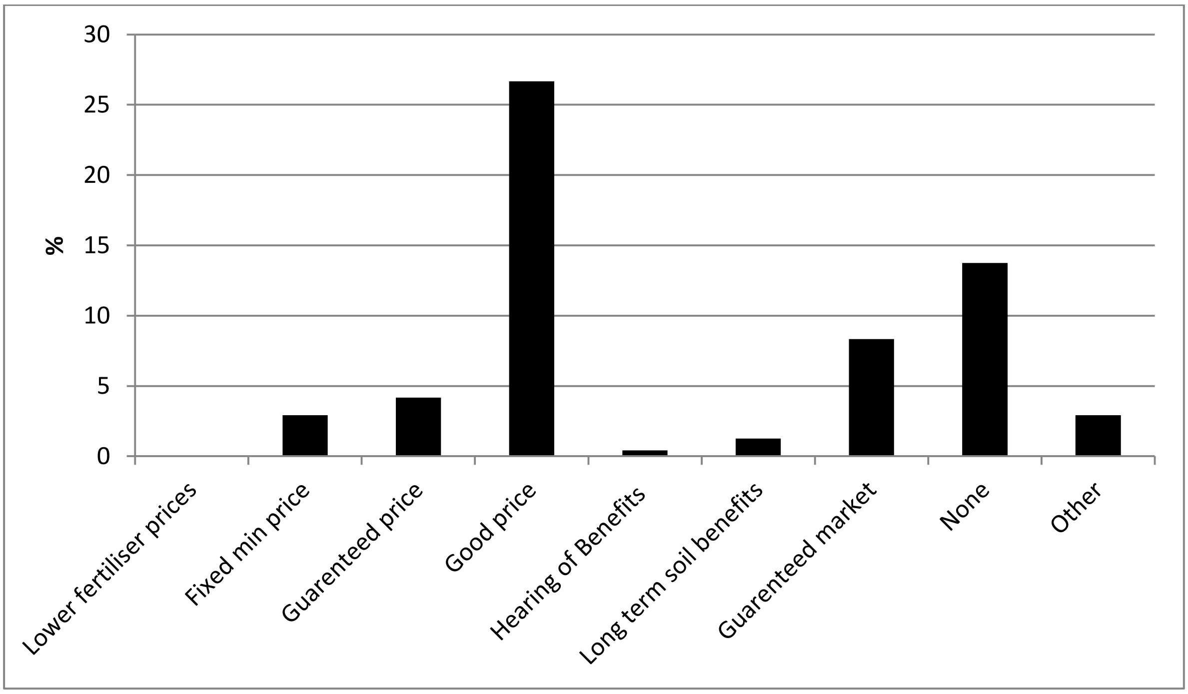

Figure 6: Incentives to encourage straw baling. Source: Glithero *et al*. (2013c)

3.5. Potential cereal straw supply

Given acceptable market or contract conditions, and based on preferences expressed in the survey, the supply of straw that farmers would be willing to sell for bioenergy purposes is presented in Table 3, based on the mean straw yields in Table 2. Of the total 2.52Mt of cereal straw available, 1.99Mt is from wheat with the remaining 529,000t from barley. The East of England contains the largest area of cereals, of both wheat and barley; however, it records the lowest (barley straw) and second lowest (wheat straw) percentage of production that farmers would be willing to supply for bioenergy purposes, at 21% and 43% respectively. However, we estimate that the East of England, on these assumptions, would supply 346kt (47kt) of wheat (barley) straw for bioenergy; the East Midlands contains the greatest potential straw for use/sale for bioenergy purposes (wheat 686kt; barley 146kt) with Yorkshire and Humber respectively producing 271kt and 150kt of wheat and barley straw. We estimate that 48% of English arable farm cereal straw would be available for sale for bioenergy production. Conversely, 35% (64%) of farmers would not supply wheat (barley) straw for bioenergy, and 31% of farmers would supply neither type of straw for bioenergy.

Table 3: Area, yields and potential supply of wheat and barley straw. Source: Glithero *et al*. (2013c)

Crop	GOR	Area in GOR	Straw Yield	Potential Total Straw (t) [1]	Potential Supply to Bioenergy (t) [2]	Percentage supply of Total [3]
Wheat	North East	62,021	2.52	156,114	87,054	55.76
	North West	24,066	2.21	53,093	35,760	67.35
	Yorkshire & the Humber	220,285	2.76	606,894	271,737	44.77
	East Midlands	340,059	3.26	1,108,195	685,874	61.89
	West Midlands	147,223	1.88	277,353	172,706	62.27
	East of England	482,895	1.66	800,943	345,843	43.18
	South East	222,206	3.34	741,744	246,356	33.21
	South West	136,923	2.23	305,467	141,804	46.42
	Total	1,635,678	2.48	4,049,803	1,987,135	49.07
Barley	North East	32,132	2.38	76,475	37,677	49.27
	North West	18,328	2.00	36,647	17,607	48.04
	Yorkshire & the Humber	90,258	3.04	274,486	150,525	54.84
	East Midlands	59,692	3.58	213,753	146,232	68.41
	West Midlands	35,096	1.81	63,449	29,364	46.28
	East of England	118,475	1.95	230,685	47,331	20.52
	South East	57,252	2.92	167,090	60,948	36.48
	South West	70,611	2.25	158,641	39,538	24.92
	Total	481,845	2.53	1,221,228	529,221	43.34
	Cereals Total	2,117,523		5,271,031	2,516,356	47.74

[1] Area in GOR multiplied by straw yield

[2] Per farm crop areas multiplied by the percentage of straw would be willing to sell for bioenergy multiplied by the regional straw yield, aggregated to GOR levels (method cited in Glithero *et al*., 2013a)

[3] Potential supply to bioenergy as a percentage of potential total straw

Estimates of straw availability for bioenergy purposes from incorporated or sold / used cereal straw are presented in Table 4. Total straw chopped and incorporated was estimated at approximately 1.5 Mt, with 840,000 tonnes available for sale across all the GORs of England. Overall, assuming straw is first diverted from that incorporated into the soil, 57% of the total straw chopped and incorporated is estimated to be available for sale for bioenergy purposes. On the assumption that straw for bioenergy would first be diverted from that straw which is currently used or sold, 1,97Mt (52%) of the straw currently sold / used would be sold for bioenergy purposes, leading to 555,000 tonnes being sourced from straw currently incorporated.

Table 4: Estimated straw incorporated and proportion of incorporated or sold / used straw that would be available for bioenergy purposes by crop type and Government Office Region. Source: Glithero *et al.* (2013c).

Crop	GOR	Area in GOR (ha)	Straw Yield t/ha	Total Straw chopped [1]	Total Straw chopped but would be sold [2]	Percentage of total chopped straw that would be sold [3]	Total Straw used [a]	Total Straw used but would be sold [b]	Percentage of total used straw that would be sold [c]
Wheat	NE	62,021	2.52	22,425	12,527	55.86	133,689	80,758	60.41
	NW	24,066	2.21	0	0		53,093	35,760	67.35
	Y&H	220,285	2.76	108,999	45,162	41.43	497,895	251,837	50.58
	EM	340,059	3.26	393,044	297,644	75.73	715,151	482,894	67.52
	WM	147,223	1.88	74,139	74,139	100.00	203,215	139,666	68.73
	EE	482,895	1.66	526,208	279,725	53.16	274,735	118,141	43.00
	SE	222,206	3.34	214,589	98,794	46.04	527,155	214,867	40.76
	SW	136,923	2.23	0	0		305,467	141,804	46.42
	Total	1,635,678	2.48	1,339,403	807,991	60.32	2,710,400	1,465,727	54.08
Barley	NE	32,132	2.38	0	0		76,475	37,677	49.27
	NW	18,328	2.00	594	450	75.76	36,053	17,463	48.44
	Y&H	90,258	3.04	0	0		274,486	150,525	54.84
	EM	59,692	3.58	2,530	2,530	100.00	211,224	143,702	68.03
	WM	35,096	1.81	0	0		63,449	29,364	46.28
	EE	118,475	1.95	127,890	27,160	21.24	102,795	20,172	19.62
	SE	57,252	2.92	0	0		167,090	60,948	36.48
	SW	70,611	2.25	0	0		158,641	39,538	24.92
	Total	481,845	2.53	131,014	30,139	23.00	1,090,214	499,388	45.81
Cereals Total		2,117,523		1,470,417	838,130	57.00	3,800,613	1,965,115	51.71

Key to GORs: NE-North East; NW-North West; Y&H-Yorkshire and the Humber; EM- East Midlands; WM-West Midlands; EE-East of England; SE-South East; SW-South West.

[1] Per farm crop areas multiplied by the percentage of area would chop multiplied by the regional straw yield, aggregated to GOR levels (method cited in Glithero *et al.*, 2013a)

[2] Per farm minimum value of either the area of straw chopped or the area of straw would be willing to be sold for bioenergy, multiplied by the regional straw yield, aggregated to GOR levels (method cited in Glithero *et al.*, 2013a)

[3] Total straw chopped but would be sold as a percentage of total straw chopped.

[a] Area in GOR multiplied by the straw yield minus the total straw chopped.

[b] Per farm minimum value of either the area of straw used or the area of straw that farmers would be willing to sell for bioenergy, multiplied by the regional straw yield, aggregated to GOR levels (method cited in Glithero *et al.*, 2013a).

[c] Total straw used that farmers would be willing to sell for bioenergy as a percentage of the total straw used.

3.6. Willingness to grow SRC and Miscanthus

Farmers were asked if they would be willing to grow SRC and miscanthus. Of the 244 responses to this question for miscanthus, 81.6% responded that they would not be willing to grow the crop, 17.2% responded that they would be willing and 1.2% noted that they already grew the crop. For SRC, 87.7% responded that they would not be willing, 11.9% responded that they would be willing and 0.4% noted that they already grew this crop; 10.7% of farmers would be willing to grow both crops and 79.9% of farmers would not be willing to grow either crop. There was no significant effect of farmer's age, education level, farm ownership, farm location (EU region), farm type and size on willingness to grow either SRC or miscanthus (p-values ranged from 0.15 to 0.97). The reasons given for being willing or not to grow miscanthus and SRC are shown in Figure 8. Land quality aspects (e.g. damage to drains, cost of land change back to an agricultural use) was the most frequently cited environmental reason for not growing SRC and miscanthus. However, these reasons also featured for growing these crops along with positive environmental impacts. Lack of appropriate machinery and committing of land for a long time period were key 'no' reasons; the key 'yes' reasons were committing land for a long time period and ease of crop management. The time to financial return and profitability were the main financial, market and knowledge reasons against growing these crops. Conversely, profitability was also the main reason for growing these crops. Respondents were able to add additional reasons that were important in their decision making and 52 farmers provided data on additional reasons. The responses from those willing to grow SRC and miscanthus related either to general interest, ethical issues or land and resource management factors, Table 5. The most common responses for not growing SRC and miscanthus were related to current farming activities and ranged from needing to continue with current arable farming activities to just being "happy" with the current activities, Table 6.

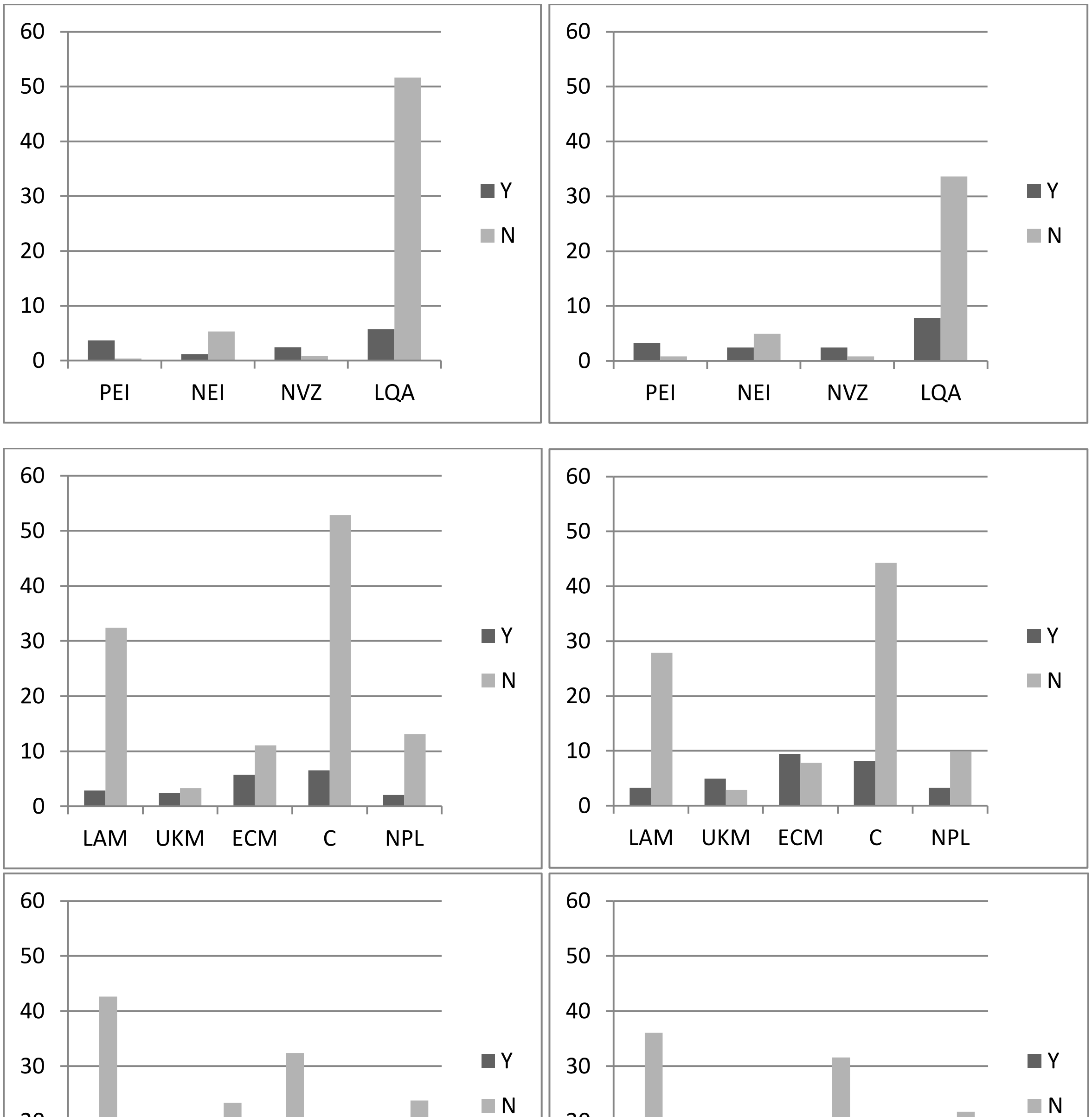

Figure 8: Left hand side SRC, right hand side miscanthus, percentage responses from those that would and would not be willing to grow the relevant crops. Top plots are environmental reasons, middle are practical aspects of the crops and bottom plots are market, financial and knowledge reasons. PEI positive environmental impact, NEI negative environmental impact, NVZ nitrate vulnerable zone restrictions, LQA land quality aspects, LAM lack of appropriate machinery, UKM use of known machinery, ECM ease of crop management, C committing the land for a long time period, NPL needing permission from landlord, TFC time to financial return on crop, MC market for crop, NMC no market for the crop, P profitability, LWE local working example and NLWE no local working example. Source: Glithero *et al.* (2013b).

Table 5: Additional comments for growing SRC and miscanthus. SRC - yes (6 comments), miscanthus - Yes (5 comments) – Already Growing (AG) (1 comment)

Category	Segment	SRC	Misc	Quotes
Yes	Interest and "Moral"	3	2	*"Moral stand point for growing energy crops"* *"Never given it any thought, but would be interested to have a look"* *"Interested in renewable energy sources"*[1]
	Land and resource management	2	2	*"Long term weed control in crop eg blackgrass"* *"Low labour input required"*
	Other	1	1	*"Not very keen though"*
AG				*"Energy payment received and within the set-aside area"*

[1] Only applicable to SRC. Source: Glithero *et al*. (2013b).

Table 6: Additional comments for not growing SRC and miscanthus. SRC - No (43 comments), miscanthus - No (45 comments)

Segment	SRC	Misc	Typical Comments - summarised	Selection of Quotes
Interest and "Moral"	6	6	• Not interested • Moral point against using land for energy crops	*"No interest in growing these crops"* *"Should not be using land for energy crops when there is a shortage of food in the world"*
Current Farming Activities	17	17	• Does not fit with organic systems • Happy with / committed to current cropping • Doesn't fit with current activities • Need straw for livestock/bedding • Already growing miscanthus/SRC	*"Need all land for grain for fat cattle and sheep"* *"No synergy with current farming activities"*
Land and Soil	8	8	• Not enough land • Soil/land not suitable • Whole farm needed to be converted • Good land for agricultural crops	*"Only got a small acreage, good land better for growing food crops"* *"Not enough land"*
Knowledge	6	7	• Looked at but decided against • Lack of knowledge of this crop • Personal observations	*"Previously investigated and decided against"* *"Lack of personal knowledge of the crops"*
Profit	2	3	• Profitability relative to other enterprises • Good arable crop prices • High cost of rhizomes[1]	*"Price of wheat and OSR are good "* *"Profitability relative to other crops"*
Other	4	4		*"Age"* *"I am a farmer, not a woodman"* [2] *"SRC needs to dry after cutting and before being sent to the power plant. Farmer has no room or facilities to dry the crop"* [2] *"Poor track record of purchasing companies"* *"Become Invasive"* [1] *"Proximity to urban area (potential fire risk)"* [1]

[1] Only applicable to miscanthus

[2] Only applicable to SRC

Source: Glithero *et al*. (2013b).

3.7. Potential supply of SRC and Miscanthus

Based on farmers' indication of their willingness to grow SRC and miscanthus, and a 9.29% conversion rate, the largest area of these crops would be in the East Midlands. Overall, the potential area of miscanthus (SRC) that could be grown on arable farm types is 89,900 ha (50,700 ha) respectively. If willing farmers converted 100% of their UAA, considerably larger amounts of DECs could be produced. Figure 9 presents the theoretical maximum areas under a 100 % UAA conversion assumption; in total, 967,500 ha of miscanthus and 545,700 ha of SRC are possible.

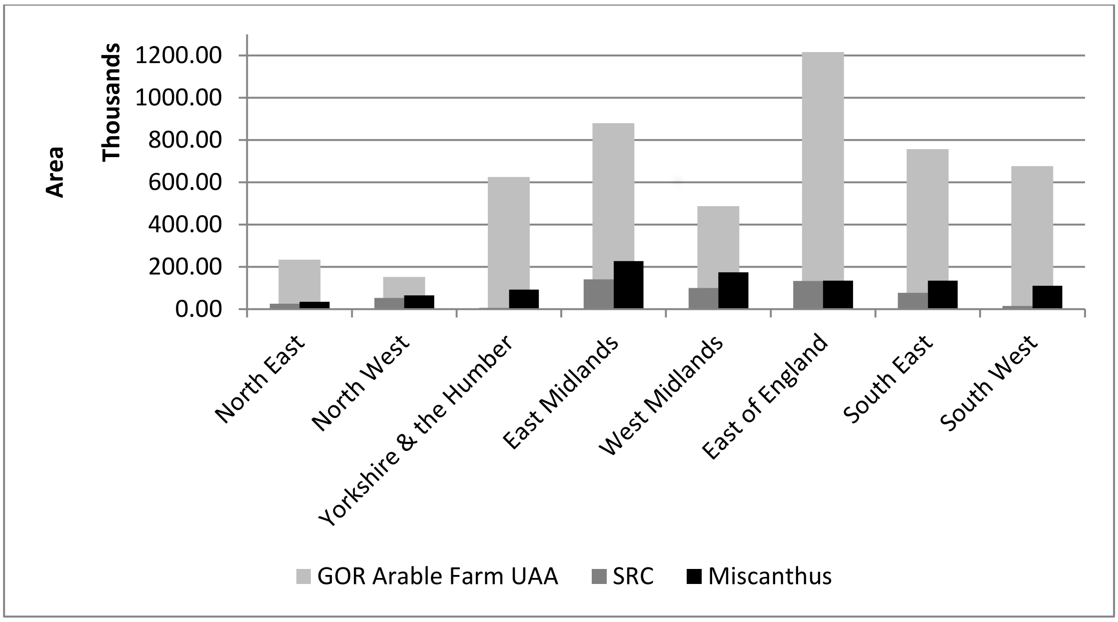

Figure 9: Potential area of SRC and miscanthus grown assuming 100% of UAA, for these farm types, is converted into these crops. Source: Glithero *et al.* (2013b).

4. Discussion and Conclusions

Our estimates indicate that approximately 5.27 Mt of wheat and barley straw is produced from arable farm types in England. However, these estimates are based on per hectare yields which display large variation across the GORs of England; spatial variation in yield has also been found in Denmark (Skott, 2011). Of this 5.27 Mt, we calculate that 2.5 Mt would *potentially* be available for bioenergy purposes (47% of the total cereal straw production). Additionally, we estimate that while 1.47 Mt of (largely wheat) cereal straw is currently chopped and incorporated, only 555,000 - 840,000t of this would be made available to bioenergy production: the range being dependent upon whether this straw supply would first be diverted from that currently marketed or used, or from that currently incorporated. Under either scenario, using cereal straw for bioenergy purposes would have a large impact on the straw market. With respect to contractual implications of supplying cereal straw, the most popular contract condition was for a fixed area of straw, for a fixed farm-gate straw price. The most frequent response for the minimum farm-gate price farmers would be willing to sell straw for bioethanol was £50t^{-1}. A three year contract was the most popular contract length preference cited. Timeliness of operations and benefits of incorporation are the main reasons why farmers incorporate straw; as one would expect from the farm perspective, a 'good price' for straw was indicated to be the best incentive to encourage straw baling. On the basis of our estimates, the greatest potential for cereal straw supply for bioenergy purposes is found in the Yorkshire and Humber, East Midlands and East of England regions. The logistics of supply chains are likely to restrict the supply of straw to bioenergy plants within these regions or which draw upon straw from these regions; potential locations for a straw-based lignocellulosic bioenergy plant in England will crucially depend upon transport distances and the economies of scale required to operate such a facility (Glithero *et al.*, 2013c). However, while straw is most likely to be sourced from within these arable areas, issues of soil carbon, organic matter and nutrient depletion remain (Powlson *et al.*, 2005; Addisu *et al.*, 2009). However, in commercial practice, even where straw is removed, a substantial proportion of the straw and stubble biomass is returned to the soil (Addiscott and Dexter, 1994; Powlson *et al.*, 2011). It is argued therefore that rotational, rather than continual, removal of straw may be sufficient to maintain soil health and organic matter status (Loveland and Webb, 2003). The benefits of straw incorporation could potentially be addressed if the process residue from bioethanol production had nutrient and soil structure benefits when applied to land.

With respect to dedicated energy crops, 81.6% (87.7%) responded that they would not be willing to grow miscanthus (SRC), 17.2% (11.9%) responded that they would be willing grow miscanthus (SRC) and 1.2% (0.4%) noted that they already grew the respective crop. Land quality concerns, committing land for a long period time, lack of appropriate machinery, time to financial return and profitability were cited as reasons for not wishing to grow these crops. Ease of crop management, profitability, committing land for a long period of time and profitability were also included as key reason for growing these crops. These findings concur with Adams *et al*. (2011) who found that the profitability of DEC and the uncertainty over the financial return were key barriers to DEC production. Our results demonstrate no link between various farm and farmer characteristics and willingness to grow these crops. Under the assumption that those farmers who are willing to consider growing miscanthus and SRC plant 9.29% of their UAA, this would lead to 89,900 ha of miscanthus and 50,700 ha of SRC on arable farm types in England; previous studies have suggested that small scale planting within a farm's UAA will be more likely than wide scale planting given modest relative economic returns (Karp *et al.*, 2010).

The results presented here indicate that there is potential for second generation feedstock supply from both cereal straw and DECs. Financial incentive policies are currently in place for DECs; however, no policies relating to straw use for bioenergy purposes exist. The results presented indicate that potentially 38%-57% of the straw that is currently chopped and incorporated would be made available for bioenergy purposes: this represents a substantial feedstock contribution. Given that policies exist to incentivise farm-level production of DECs, policy makers could consider incentives for cereal straw supply for bioenergy purposes. Alternatively, support for DECs could be reduced in order to place both DECs and cereal straw on the same economic basis as potential feedstocks. While policy incentives alone may not encourage straw sales, as observed with incentives for establishing dedicated energy crops (Sherrington and Moran, 2010), incentivising farmers to supply a co-product from cereal production is likely to lead to greater uptake of feedstock supply than for dedicated energy crops. Such policy intervention may require price stabilisation of feedstock markets in conjunction with more rational levels of support for feedstock derived from dedicated energy crops and that provided from co-products.

In conclusion, we identify a significant potential supply of second generation bioenergy feedstock in England. However, if agriculture is required to produce both food and fuel-feedstock, policy messages need to be more integrated to avoid the unintentional consequences that have compromised agricultural policy objectives in the past. The UK Code of Good Agricultural Practice (Anon, 2009) includes the statement: “incorporating crop residues that do not contain much nitrogen, such as cereal straw, into the soil in autumn will help to reduce the amount of nitrate leached and to maintain or increase soil organic matter”. Removal of these residues presumably reduces these environmental benefits but may lead to greater wider benefits if used as a fuel-feedstock, particularly if technological progress is achieved in the conversion of lignocellulosic biomass into bioethanol. Quantifying the local and global environmental, economic and societal benefits and the associated costs is a necessary requirement before appropriate policies can be devised.

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References:

Addiscott, T.M. and Dexter, A.R. (1994). Tillage and crop residue management effects on losses of chemicals from soils, *Soil Tillage Research*, **30**, 125-68.

Addisu, M., Snape, J.W., Simmonds, J.R. and Gooding, M.J. (2009). Reduced height (*Rht*) and photoperiod insensitivity (*Ppd*) allele associations with establishment and early growth of wheat in contrasting production systems, *Euphytica*, **166(2)**, 249-67.

Anon (2009). Protecting our water, soil and air a code of good agricultural practice for farmers, growers and land managers. DEFRA.

Anon (2011). Crop areas, livestock populations and agricultural workforce 2011 England – final results. Defra.

Anon (2012). http://www.ukerc.ac.uk/support/BSBEC_homepage.

Cassman, K.G. and Liska, A.J. (2007). Food and fuels for all: realistic or foolish? *Biofuels, Bioproducts and Biorefining*, **1(1)**,18-23.

Cherubinia, F. and Ulgiatib, S. (2010). Crop residues as raw materials for biorefinery systems – A LCA case study. *Applied Energy*, **87**, 47-57.

Copeland, J. and Turley, D. (2008). *National and regional supply/demand balance for agricultural straw in Great Britain*. CSL.

Environmental Audit Committee (2008). Are biofuels sustainable?. House of Commons, http://www.publications.parliament.uk/pa/cm200708/cmselect/cmenvaud/76/7602.htm

Ericsson, K., Rosenquist, H. and Nilsson, L.J. (2009). Energy crop production costs in the EU, *Biomass and Bioenergy*, **33**, 1577-86.

Finch, J.W., Karp, A., McCabe, D.P.M., Nixon, S., Riche, A.B. and Whitmore, A.P. (2009). *Miscanthus, short-rotation coppice and the historic environment*. English Heritage Report.

Glithero, N.J., Ramsden, S.J. and Wilson, P. (2012). Farm systems assessment of bioenergy feedstock production: Integrating bio-economic models and life cycle analysis approaches, *Agricultural Systems*, **109**, 53-64.

Glithero, N., Wilson, P. and Ramsden, S.J. (2013a). Straw Use and Availability for Second Generation Biofuels in England, *Biomass and Bioenergy* (in press). 10.1016/j.biombioe.2013.02.033

Glithero, N., Wilson, P. and Ramsden, S.J. (2013b). Prospects for arable farm uptake of Short Rotation Coppice willow and miscanthus in England, *Applied Energy* (in press). http://dx.doi.org/10.1016/j.apenergy.2013.02.032

Glithero, N., Ramsden, S.J. and Wilson, P. (2013c). Barriers and Incentives for cereal straw based bioethanol: a farm business perspective, *Energy Policy* (in press). 10.1016/j.enpol.2013.03.003

Karp, A. and Shield, I. (2008). Bioenergy from plants and the sustainable yield challenge, *The New Phytolologist*, **179**, 15-32.

Karp, A. et al (2010). *Social, Economic and Environmental Implications of Increasing Rural Land Use under Energy Crops*: Full Research Report, ESRC End of Award Report, RES-227-25-0020. Swindon: ESRC; 2010.

Lal, R. (2008). Crop residues as soil amendments and feedstock for bioethanol production, *Waste Management*, **28**, 747–758.

Londo, M., Lensink, S., Wakker, A., Fischer, G., Prieler, S., van Velthuizen, H., de Wit, M., Faaij, A., Junginger, M., Berndes, G., Hansson, J., Egeskog, A., Duer, H., Lundbaek, J., Wisniewski, G., Kupczyk, A. and Könighofer, K. (2010). The REFUEL EU road map for biofuels in transport: Application of the project's tools to some short-term policy issues, *Biomass and Bioenergy*, **34**, 244-250.

Loveland, P. and Webb, J (2003). Is there a critical level of organic matter in the agricultural soils of temperate regions: a review, *Soil Tillage Research*, **70 (1)**, 1-18.

Mitchell, C. and Connor, P. (2004). Renewable Energy Policy in the UK 1990-2003, *Energy Policy*, **17**, 1935-1947.

Naik, S.N., Goud, V.V., Rout, P.K. and Dalai, A.K. (2010). Production of first and second generation biofuels: A comprehensive review, *Renewable and Sustainable Energy Reviews*, **14(2)**, 578-597.

Nigam, P.S. and Singh, A. (2011). Production of liquid biofuels from renewable resources, *Progress in Energy and Combustion Science*, **37(1)**, 52-68.

Nix J. (2011). Farm Management Pocketbook. 42nd (2012) ed. Agro Business Consultants Ltd.

Oppenheim, A.N. (2011). *Questionnaire Design, Interviewing and Attitude Measurement*. New edition.

Pimentel, D., Marklein, A., Toth, M., Karpoff, M., Paul, G., McCormack, R., Kyriaziz, J. and Kruger, T. (2008). Biofuel Impacts on World Food Supply: Use of Fossil Fuel, Land and Water Resources, *Energies,* **1(2)**, 41-78.

Powlson, D.S., Glendining, M.J., Coleman, K. and Whitmore, A.P. (2011). Implications for soil properties of removing cereal straw: results from long-term studies, *Agronomy Journal*, **103(1)**, 279-87.

Powlson, D.S., Riche, A.B. and Shield, I. (2005). Biofuels and other approaches for decreasing fossil fuel emissions from agriculture, *Annals of Applied Biology*, **146**, 193-201.

Sherrington, C., Bartley, J. and Moran, D. (2008). Farm-level constraints on the domestic supply of perennial energy crops in the UK, *Energy Policy*, **36**, 2504-12.

Sherrington, C. and Moran, D. (2010). Modelling farmer uptake of perennial energy crops in the UK, *Energy Policy*, **38**, 3567-78.

Sims, R., Taylor, M., Saddler, J. and Mabee, W. (2008). *From 1st- to 2nd-generation biofuel technologies: An overview of current industry and RD&R activities*. IEA.

Skott T. Straw to Energy status, tech and innovation in Denmark 2011. INBIOM; 2011.

Slade, R., Panoutsou, C. and Bauen, A. (2009). Reconciling bio-energy policy and delivery in the UK: Will UK policy initiatives lead to increased deployment? *Biomass and Bioenergy*, **33(4)**, 679-88.
Thornley, P. and Cooper D. (2008). The effectiveness of policy instruments in promoting bioenergy, *Biomass and Bioenergy*, **32(10)**, 903-13.

Thornley, P., Upham, P. and Tomei, J. (2009). Sustainability constraints on UK bioenergy development, *Energy Policy*, **37**, 5623-5635.

Williams, N. (2008). Biofuel debate deepens, *Current Biology*, **18(19)**, R891-2.

Zhang, Z., Lohr, L., Escalante, C. and Wetzstein, M. (2010). Food versus fuel: What do prices tell us?. *Energy Policy*, **38(1)**, 445-51.