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How much grassland biomass is available in Ireland in excess of livestock requirements?

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Grassland is a dominant biomass resource in Ireland and underpins most animal production systems. However, other commercial uses for grassland biomass exist, including, for example, the production of biogas through anaerobic digestion for the generation of heat, electricity and transport fuel. The objective of this study was to estimate the annual grassland resource available in Ireland in excess of livestock requirements under six contrasting scenarios. Under current grassland management and production practices there is an estimated average annual grassland resource of *ca*. 1.7 million tonnes of dry matter (DM) available in excess of livestock requirements. Only a small proportion of this resource (0.39 million tonnes of DM per annum) would be available if the targets set out in 'Food Harvest 2020' were achieved. However, increasing nitrogen (N) fertiliser input (to the limit permitted by the E.U. Nitrates Directive) combined with increasing the grazed grass utilisation rate of cattle (from 0.60 to 0.80 kg DM ingested by livestock per kg DM grown) has the potential to significantly increase this average resource to 12.2 million t DM/annum, even when allowing for achievement of 'Food Harvest 2020' targets. Under these scenarios, alternative uses for grassland biomass such as anaerobic digestion and green biorefining would not compete with traditional dairy, beef and lamb production systems, but could provide an alternative enterprise and income to farmers.

Keywords: alternative applications; biomass yield; grass; silage

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Introduction

The need to develop alternatives to non-renewable fossil-based resources has stimulated an interest in the use of plant biomass to provide renewable energy, chemicals and materials (Sanders, Scott and Mooibroek 2005). Grassland is a dominant biomass resource in Ireland accounting for approximately 92% of the agricultural land area (CSO 2012a). Not only is grassland plentiful, but some of the highest non-irrigated herbage yields (12 to 16 t dry matter (DM)/ha per annum) in Europe can also be achieved (O'Donovan, Lewis and O'Kiely 2011). These grasslands contribute substantially to Irish agricultural production systems providing a large proportion of the feed requirements of ruminant livestock (O'Mara 2008).

A range of potentially competing uses for grassland biomass exist. For example, grass and grass silage are excellent feedstocks for anaerobic digestion and the resulting biogas can be used to generate heat and electricity (Al Seadi *et al*. 2008) or can be upgraded to biomethane for use as a transport fuel (Korres *et al*. 2010). Smyth, Murphy and O'Brien (2009) reported that 10% of the grassland area in Ireland could fuel approximately 1.05 million cars (up to 55% of all passenger cars) with compressed biomethane. Furthermore, grassland biomass could be used as a fuel for thermal combustion (Prochnow *et al*. 2009). In addition, grassland derived biomass could be processed in a 'Green Biorefinery' to recover or produce a spectrum of marketable products including lactic acid and amino acids (Ecker *et al*. 2012), thermal insulation (Grass 2004) and bio-composite material (Sharma *et al*. 2012). O'Keeffe *et al*. (2011, 2012) recently proposed an Irish Green Biorefinery utilising a 2-cut grass silage system to produce thermal insulation material and a protein-rich animal feed.

The objective of this study was to estimate the average annual and potential grassland biomass resource in Ireland, in excess of the feed requirements of the national cattle herd and sheep flock, which could be available for alternative applications. This was calculated as the difference between grassland supply and grassland requirement under six contrasting scenarios.

Background and Assumptions

Grassland supply

Grassland in Ireland Approximately 92% of the 4.19 million hectares of land used for agriculture in Ireland is grassland (CSO 2012a), and this provides most of the feed requirements of the ruminant livestock population (O'Donovan *et al*. 2011). Of this grassland area, 59, 25, 11 and 5% is devoted to pasture, silage, rough grazing and hay, respectively (CSO 2012a). Rough grazing includes grazed unreclaimable bogland, and grazed mountain and lowland partially covered in scrub, bushes or rock (Hennessy *et al*. 2012). Due to the difficulty in estimating its annual herbage DM yield, the area under rough grazing was not included in this analysis.

Silage and hay production systems The average proportion of the total grass silage area (1.1 million ha) harvested for first, second and subsequent silage harvests is 78, 21 and 1%, respectively (O'Donovan *et al*. 2011). Given the infrequency of 3-cut silage systems in Ireland, these systems were not included in this analysis and the proportion of the total silage area allocated to the 1- and 2-cut silage systems was revised to 79 and 21% of the grass silage area, respectively.

Harvesting was assumed to take place on 12 June for the 1-cut silage system and on 29 May and 24 July for the 2-cut silage system. Harvesting for hay (213,200 ha) was assumed to take place on 26 June. It was assumed that no spring-grazing took place and that this herbage was captured in the silage and hay harvests. In addition, the area devoted to silage and hay was assumed to revert to grazing after the final harvest for conservation was removed.

Nitrogen (N) fertiliser application There is considerable variation in the quantities of N fertiliser used on Irish farms reflecting differences in desired yield, soil type and fertility. For the purposes of this study, assumptions for annual inorganic N input were based on the average national N fertiliser application rates in 2008 for grazed grass (65 kg N/ha), silage (101 kg N/ha) and hay (54 kg N/ha), as reported by Lalor *et al*. (2010). The average national N fertiliser application rate for silage is the average of all silage production systems and does not distinguish between a 1- and 2-cut silage system. Consequently, the inorganic N input was assumed to be 80 and 42 kg N/ha for first and second silage harvests, respectively (i.e. (80 + x)/2 = 101 kg N/ha; x = 122 kg N/ha for the 2-cut silage system).

Soil group Grasslands were classified into three major soil groups according to data reported in the 2011 National Farm Survey (Hennessy *et al*. 2012). The proportion of grassland (including grassland devoted to pasture, the 1- and 2-cut silage and hay systems) allocated to soil groups 1, 2 and 3 was 0.49, 0.40 and 0.11, respectively. Soil group 1 can grow the largest range of crops with few limitations, while soil group 3 has a limited use range (Gardiner and Radford 1980).

Estimated DM yield In the absence of adequate herbage DM yield data from sites across the country, yield data were derived from the N response curve reported by Finneran *et al*. (2012) which used multi-year data from perennial ryegrass plots from productive soils at three Teagasc sites, Grange (53° 31′ N, 06° 39′ W), Ballyhaise (54° 03′ N, 07° 19′ W) and Moorepark (52° 9′ N, 8° 15′ W). Finneran *et al*. (2011) calculated mean quadratic N response functions for each week of the year at the three sites and reported average annual grass growth distribution curves for each site at different N application rates. Dry matter yield data from the three sites were averaged to provide a national value. No detailed and reliable quantitative data are available on the productive capacity of grasslands in soil groups 1, 2 and 3. In the absence of such data, all DM yield data were adjusted downwards for grassland in soil groups 1 (-15%), 2 (-20%) and 3 (-30%) to estimate the on-farm outputs relative to the response to the management conditions employed at Grange, Ballyhaise and Moorepark.

(i) Grazed grass:

The annual DM yield for grazed grassland was calculated as a function of the 2008 annual N application rate for pasture (i.e. 65 kg N/ha).

(ii) Grass silage:

The annual DM yield for the grassland area under the 1- and 2-cut silage systems was calculated as follows:

Grass growth distribution curves were calculated as a function of a N application rate of 95 and 137 kg N/ha for the 1- and 2-cut silage systems, respectively. This represents an annual inorganic N input of 80 and 122 kg N/ha for the 1- and 2-cut silage systems, respectively. In addition, the silage area was assumed to revert to grazing after the final harvest was removed.

The N application rate for post-harvest grazing was assumed to be 15 kg N/ha (i.e. 16.25 m^3 slurry/ha or 50% of the maximum slurry N fertiliser value; Lalor *et al*. 2010).

The herbage DM yield harvested for silage was calculated as the sum of weekly grassland DM yield up to the silage harvest date (averaged across the three sites). These grass growth distribution curves are derived from a simulated grazing system at four-weekly intervals. However, the DM yield after longer growth intervals (e.g. 13 weeks for the 1-cut silage system) would be expected to exceed the sum of four-weekly harvests within the same time frame (Binnie and Chestnutt 1991). A yield adjustment factor [yield adjustment factor = $-(0.00025 \times w^3) + (0.00015 \times w^2) + (0.07779 \times w) + 0.70121$ [for all $w > 4$]; where w = number of weeks between the start of spring growth (13th March) and the silage harvest date] was subsequently included to reflect this longer harvest interval (Finneran *et al*. 2011). This yield adjustment factor was only applied to the first harvest of the 2-cut silage system, as the DM yield of regrowth for the second silage harvest was assumed not to exceed the sum of four-weekly harvests.

Following high-yielding silage harvests, a delay in sward regrowth generally occurs, as the capacity of the defoliated plant to intercept solar radiation is reduced (Doyle and Edwards 1986). The exponential function [$d = 15/(1 + \mathrm{Exp}(-1.67(\mathrm{DM\ yield} - 5.58)))$; where d = number of days delay of regrowth] described by Doyle and Edwards (1986) was used to quantify this delay in regrowth prior to the silage area reverting to the grazing system.

The potential grazed herbage DM yield post-silage harvesting was subsequently calculated as the sum of the weekly grassland DM yield over the remainder of the grazing season (averaged across the three sites). The DM yield of the grassland area under silage was calculated as the sum of the herbage DM yield harvested for silage and the potential grazed herbage DM yield post-silage harvesting.

(iii) Hay

The annual DM yield for the grassland area under hay was calculated as described for grass silage, but with an annual N application rate of 69 kg N/ha (i.e. 54 kg N from inorganic N fertiliser and 15 kg N from slurry). It was assumed that the area reverted to grazing post-harvesting on 26 June.

Grassland requirement

Animal categories and numbers The total number of cattle (i.e. dairy and beef) and sheep in Ireland and how it is categorised (i.e. by age and type) was derived from the mean of numbers reported in the 2011 June and December Livestock Surveys published by the Central Statistics Office (CSO 2012a,b).

Cattle In developing greenhouse gas emission factors for the Irish cattle herd, O'Mara (2006) calculated the annual (i.e. year 2003) grass, grass silage and concentrate DM intake requirements for each of the cattle categories outlined in the Livestock Survey (CSO 2012a,b). Briefly, this process involved (a) dividing the country into three regions differing in duration of winter housing and indoor feeding practices, (b) defining the production system in each region in terms of calving date, dates of winter housing and spring turnout to pasture, live-weight, forage type offered and lactation length, etc., (c) calculating the daily energy requirements of cattle in each region based on maintenance requirements, milk yield and composition, requirements for foetal growth and gain or loss of body weight, etc., as appropriate and (d) calculating the composition of the diet of cattle in each region based on their daily energy requirements.

These DM intake requirements were outlined for each of the cattle categories by region and by dairy and beef production system (e.g. Dairy system: (a) spring calving cows, calving date 9 February, (b) spring calving cows, calving date 9 March, (c) spring calving cows, calving date 6 April and (d) autumn-calving cows). Annual concentrate supplementation of grazed grass and grass silage diets was also calculated by O'Mara (2006). For example, on average (weighted by proportion of the herd in each region and production system) grazed grass, grass silage and concentrates accounted for 62, 23 and 15%, and 62, 37 and 1% of the annual DM intake requirements of the dairy and 'other cattle' category, respectively. However, for the purposes of this study, only data on the annual grass and grass silage DM intake requirements are presented, and it was assumed that the rates of annual concentrate DM intake outlined by O'Mara (2006) continue to be appropriate to each cattle category. A weighted average (by proportion of the herd in each region and production system) of the annual grass and grass silage DM intake requirements was taken for each category of cattle.

Sheep The annual DM intake requirements for the 'ewes two years of age and over' and 'lamb' categories outlined in the Livestock Survey (CSO 2012a,b) were derived from data provided by Keady (personal communication), and reflect current on-farm inputs. Only the annual grass and grass silage DM intake requirements were used in this analysis. Grazed grass and grass silage were assumed to account for 90% and 10% of the annual herbage DM requirement for each sheep group, respectively (Keady, Hanrahan and Flanagan 2009). To calculate the DM intake requirement of 'lambs', a weighted average (across the growing season and accounting for drafting of lambs for slaughter) of the daily DM intake was first calculated for 'lambs for drafting' (i.e. 0.52 kg DM/d from 15 March to 1 December) and for 'replacement ewe lambs' (i.e. 1.37 kg DM/d from 2 December year 1 to 1 December year 2). The annual grass and grass silage DM intake requirement was then calculated based on the assumption that 'lambs for drafting' represent 75% of this group. In the absence of adequate intake data, the annual DM intake for 'ewes under two years of age' and 'rams' was assumed to be 90% of the annual DM intake requirements of 'ewes two years of age and over'.

Grass and grass silage utilisation rates The efficiency of grass utilisation on the average Irish dairy and beef suckler farm is approximately 0.60 kg grass DM ingested by livestock per kg grass DM grown (Lapple, Hennessy and O'Donovan 2012; Crosson 2007). This implies that the effective DM supply across grassland-based dairy and beef systems is *ca*. 67% higher than the actual DM requirement of the cattle. The grass utilisation rate on the average sheep farm is assumed to be higher, at 0.80 kg grass DM ingested by livestock per kg grass DM grown (Keady, personal communication). Similarly, when considering grass silage DM requirement, potential losses from harvesting, effluent production, fermentation, and aerobic deterioration during storage and at feedout also need to be considered (McDonald, Henderson and Heron 1991). The efficiency of grass silage utilisation on dairy, beef and sheep farms is assumed to be 0.73 kg silage DM per kg grass DM grown (O'Kiely, personal communication).

Other livestock The annual DM requirement of other livestock groups (e.g. pigs, horses, donkeys, goats, deer, etc.) was not included in this analysis and was assumed to be offset against the annual DM supply of the grassland area under rough grazing (447,300 ha; CSO 2012a).

Scenarios investigated

Six contrasting scenarios were investigated to estimate the annual and potential grassland biomass resource in Ireland, which could be available for alternative uses:

Benchmark value – Scenario 1: The annual available grassland resource, in excess of the requirements of the national cattle herd and sheep flock, was calculated based on the difference between current estimated grassland supply and requirements as outlined above.

Maximum N fertiliser application – Scenario 2: Grassland supply was calculated based on the maximum annual rate of N fertiliser application allowed under statutory limits (DAF 2006) and as outlined by current recommendations (Coulter and Lalor 2008). Based on these recommendations, the assumed maximum N fertiliser application rates were 182 (based on 1.52 livestock units/ha with animals housed indoors 0.34 of the year (Hennessy *et al*. 2012)), 125, 225 and 80 kg N/ha for grazed grass, 1-cut silage system, 2-cut silage system and hay, respectively. The grassland area devoted to silage and hay is assumed to revert to grazing post-harvest. In addition, the N application rate for post-harvest grazing was 57 (i.e. maximum N fertiliser application rate for grazed grass minus maximum N fertiliser application rate for the 1-cut silage system), 44 (as for the 1-cut silage system, but revised downwards to reflect the shorter post-harvest grazing period) and 102 (i.e. maximum N fertiliser application rate for grazed grass minus maximum N fertiliser application rate for hay) kg N/ha for the 1-cut silage, 2-cut silage and hay systems, respectively. Grass growth distribution curves were calculated as a function of N application (Finneran *et al*. 2011) and herbage DM yield data were calculated as outlined above. Grassland requirement was calculated as in Scenario 1.

Increased grass utilisation rate of cattle – Scenario 3: The Sectoral Road Maps for dairying and suckler-beef systems for 2018 (Teagasc 2011a,b) have targeted an increase in the amount of herbage utilised from 6.4 to 8.7 (i.e. from 0.60 to 0.82 kg grass DM ingested by livestock per kg grass DM grown) and 4.8 to 6.0 (i.e. from 0.60 to 0.76 kg grass DM ingested by livestock per kg grass DM grown) t DM/ha, respectively. Grassland supply and requirement were calculated as in Scenario 1, but the efficiency of grass utilisation (by grazing) on all cattle farms was assumed to be 0.80 kg grass DM ingested by livestock per kg grass DM grown. The grass silage utilisation rate (on all farms) and the grass utilisation rate for sheep remained unchanged.

Maximum N fertiliser application and increased grass utilisation rate of cattle – Scenario 4: Grassland supply was calculated as in Scenario 2, while grassland requirement was calculated as outlined in Scenario 3.

Implementation of Food Harvest 2020 – Scenario 5: The 'Food Harvest 2020' report (DAFF 2010) sets ambitious targets for growth in the value and volume of production from the Irish agri-food sector, including an increase of 50% in milk production and an increase in the output value of the beef and sheep sectors by 40 and 20%, respectively, relative to the period 2007 to 2009. Achievement of these targets is likely to result in changes in the size and composition of the national herd. Grassland supply was calculated as in Scenario 1. Grassland requirement was determined as in Scenario 1, but was based on predicted livestock numbers in Ireland following the achievement of the Food Harvest 2020 targets for the dairy, beef and sheep sectors (Donnellan and Hanrahan 2011). The total number of cattle and sheep in 2020 were derived from the mean of numbers reported by Donnellan and Hanrahan (2011) for the pasture and housing periods.

Implementation of Food Harvest 2020, maximum N fertiliser application and increased grass utilisation rate of cattle – Scenario 6: Grassland supply was calculated as in Scenario 2. Grassland requirement was calculated as in Scenario 5, but the efficiency of grass utilisation (by grazing) on all cattle farms was assumed to be 0.80 kg grass DM ingested by livestock per kg grass DM grown. The grass silage utilisation rate (on all farms) and the grass utilisation rate for sheep remained unchanged.

Results and Discussion

Scenario outputs

The average annual grassland supply and requirement (t DM) for each of the six scenarios investigated are presented in Tables 1 and 2, respectively. The grassland management and production practices outlined for Scenario 1 indicate that there is a current average annual grassland resource of *ca.* 1.7 million t DM available in excess of livestock requirements (Table 3). Alternative forages such as maize silage (19,000 ha; CSO 2012a), arable silage (2,900 ha; CSO 2012a) and forage brassicas (1,300 ha; CSO 2012a) also make a small contribution to the feed requirements of cattle and sheep, and their inclusion in this analysis would be expected to further increase the grassland resource available for alternative applications.

As expected, increasing N fertiliser input (Scenario 2) resulted in a substantial increase in grass supply and this has the potential to increase the average annual available grass resource to 9.3 million t DM. There appears to be considerable scope for increasing N fertiliser inputs to increase grassland productivity, with current fertiliser N usage being considerably lower than the advice given even when assuming that slurry N fertiliser value was also being maximised (i.e. 33 m^3/ha = *ca*. 30 kg/ha N; Lalor *et al*. 2010). For example, current recommended N application rates for the production of grass silage, based on crop nutrient requirements and constrained by statutory limits (DAF 2006), are 125 kg/ha for the first harvest and 100 kg/ha for second or subsequent harvests (Coulter and Lalor 2008). However, the N fertiliser application rates used in Scenario 1 were considerably lower at 80 and 42 kg N/ha for the first and second silage harvests, respectively.

Current on-farm grass utilisation (by grazing) rates are relatively low (0.60 kg grass DM ingested by livestock per kg grass DM grown) with significant potential for improvement through increased stocking rates and greater adoption of currently advised grassland management technologies (Creighton *et al*. 2011). Increasing the grass utilisation rate of cattle to 0.80 kg grass DM ingested by livestock per kg grass DM grown (Scenario 3) resulted in a substantial decrease in the total grassland requirement and this has the potential to increase the average annual available grassland resource to 5.6 million t DM. The Sectoral Road Maps for dairying and suckler-beef systems for 2018 (Teagasc 2011a, b) have targeted an increase in the amount of herbage utilised from 6.4 to 8.7 (0.82 kg grass DM ingested by livestock per kg grass DM grown) and

Table 1. Annual grass supply

Scenario[1]	Soil group[2]	Grassland area and supply[3]								Annual grass supply[4] (t DM)
		Grazed grass		1-cut silage system		2-cut silage system		Hay		
		Area (ha)	Yield (t DM/ha)	Area (ha)	Yield (t DM/ha)	Area (ha)	Yield (t DM/ha)	Area (ha)	Yield (t DM/ha)	
1, 3 and 5	Total area	2,459,300	–	845,458	–	224,742	–	213,200	–	–
	Soil group 1	1,191,531	6.94	409,624	8.33	108,887	8.94	103,295	7.66	13,448,366
	Soil group 2	991,590	6.53	340,889	7.84	90,616	8.42	85,962	7.21	10,533,369
	Soil group 3	276,179	5.72	94,945	6.86	25,239	7.36	23,942	6.31	2,567,052
									Total	**26,548,787**
2, 4 and 6	Total area	2,459,300	–	845,458	–	224,742	–	213,200	–	–
	Soil group 1	1,191,531	9.36	409,624	9.76	108,887	10.66	103,295	9.63	17,307,765
	Soil group 2	991,590	8.81	340,889	9.19	90,616	10.03	85,962	9.06	13,556,226
	Soil group 3	276,179	7.71	94,945	8.04	25,239	8.78	23,942	7.93	3,303,742
									Total	**34,167,732**

[1]Annual N fertiliser application rates were 65, 95, 137 and 69 kg N/ha (Scenarios 1, 3 and 5) and 182, 182, 269 and 182 kg N/ha (Scenarios 2, 4 and 6) for grazed grass, the 1-cut silage, the 2-cut silage system and the hay system, respectively.
[2]The proportion of total grassland area (including the area of grazed grass, grass for 1-cut silage system, grass for 2-cut silage system and grass for hay) allocated to soil groups 1, 2 and 3 was 49, 40 and 11%, respectively (Hennessy *et al*. 2012). Soil group is an indicator of soil productivity potential.
[3]59, 25 and 5% of the total area of grassland in Ireland is devoted to pasture, silage and hay, respectively (CSO, 2012a). 79 and 21% of silage area was allocated to the 1- and 2-cut silage systems, respectively (O'Donovan *et al*. 2011). Yield data were calculated as a function of annual N application rates as reported by Finneran *et al*. (2011) and these are the yield estimates presented above. Yield data for silage and hay production systems were adjusted to reflect the longer harvest interval between the start of grass growth and harvesting and the return of the grassland area to grazing post-harvesting. Yield data were also adjusted for grassland in soil groups 1 (-15%), 2 (-20%) and 3 (-30%).
[4]Annual grass supply = (area of grazed grass * yield) + (area of grass for silage * yield) + (area of grass for hay * yield).

Table 2. Annual grass requirement

Scenario	Animal category	Animal numbers	Grass intake[1] (kg DM/head)	Silage intake (kg DM/head)	Grass requirement[2] (kg DM/head)	Silage requirement[3] (kg DM/head)	Total requirement[4] (kg DM/head)	Annual grass requirement[5] (t DM)
1 and 2	*Cattle*							
	Dairy cows	1,086,100	2937	1091	4895	1495	6390	6,939,658
	Other cows	1,093,300	2125	1269	3542	1738	5280	5,772,649
	Bulls (breeding only)	38,400	2125	1269	3542	1738	5280	202,753
	Cattle male: 2 years and over	300,200	1390	103	2317	141	2458	737,820
	Cattle female: 2 years and over	349,500	1221	573	2035	785	2820	985,566
	Cattle male: 1-2 years	651,550	1546	930	2577	1274	3851	2,508,884
	Cattle female: 1-2 years	833,350	1221	573	2035	785	2820	2,349,990
	Cattle male: under 1 year	896,950	533	495	888	678	1566	1,404,996
	Cattle female: under 1 year	959,800	556	477	927	653	1580	1,516,572
	Sheep							
	Ewes: lowland & upland	1,935,550	584	65	730	89	819	1,585,295
	Other sheep > 1 year	507,450	526	59	657	80	737	374,060
	Rams	73,550	526	59	657	80	737	54,216
	Other sheep (mainly lambs)	1,559,050	204	23	255	32	287	446,679
							Total	**24,879,139**
3 and 4	*Cattle*							
	Dairy cows	1,086,100	2937	1091	3671	1495	5166	5,610,543
	Other cows	1,093,300	2125	1269	2656	1738	4395	4,804,623
	Bulls (breeding only)	38,400	2125	1269	2656	1738	4395	168,753
	Cattle male: 2 years and over	300,200	1390	103	1738	141	1879	563,954
	Cattle female: 2 years and over	349,500	1221	573	1526	785	2311	807,758
	Cattle male: 1-2 years	651,550	1546	930	1933	1274	3206	2,089,177
	Cattle female: 1-2 years	833,350	1221	573	1526	785	2311	1,926,023
	Cattle male: under 1 year	896,950	533	495	666	678	1344	1,205,799
	Cattle female: under 1 year	959,800	556	477	695	653	1348	1,294,218
	Sheep							
	Ewes: lowland & upland	1,935,550	584	65	730	89	819	1,585,295
	Other sheep > 1 year	507,450	526	59	657	80	737	374,060

(**Table 2** Continued)

Scenario	Animal category	Animal numbers	Grass intake[1] (kg DM/head)	Silage intake (kg DM/head)	Grass requirement[2] (kg DM/head)	Silage requirement[3] (kg DM/head)	Total requirement[4] (kg DM/head)	Annual grass requirement[5] (t DM)
	Rams	73,550	526	59	657	80	737	54,216
	Other sheep (mainly lambs)	1,559,050	204	23	255	32	287	446,679
							Total	**20,931,099**
5	*Cattle*							
	Dairy cows	1,394,850	2937	1091	4895	1495	6390	8,912,423
	Other cows	951,400	2125	1269	3542	1738	5280	5,023,414
	Bulls (breeding only)	61,400	2125	1269	3542	1738	5280	324,193
	Cattle male: 2 years and over	407,600	1390	103	2317	141	2458	1,001,784
	Cattle female: 2 years and over	232,400	1221	573	2035	785	2820	655,352
	Cattle male: 1-2 years	717,650	1546	930	2577	1274	3851	2,763,411
	Cattle female: 1-2 years	862,750	1221	573	2035	785	2820	2,432,896
	Cattle male: under 1 year	721,200	533	495	888	678	1566	1,129,699
	Cattle female: under 1 year	700,050	556	477	927	653	1580	1,106,143
	Sheep							
	Ewes: lowland & upland	2,412,500	584	65	730	89	819	1,975,937
	Other sheep > 1 year	109,800	526	59	657	80	737	80,938
	Rams	72,400	526	59	657	80	737	53,369
	Other sheep (mainly lambs)	2,425,500	204	23	255	32	287	694,922
							Total	**26,154,480**
6	*Cattle*							
	Dairy cows	1,394,850	2937	1091	3671	1495	5166	7,205,475
	Other cows	951,400	2125	1269	2656	1738	4395	4,181,028
	Bulls (breeding only)	61,400	2125	1269	2656	1738	4395	269,829
	Cattle male: 2 years and over	407,600	1390	103	1738	141	1879	765,716
	Cattle female: 2 years and over	232,400	1221	573	1526	785	2311	537,119
	Cattle male: 1-2 years	717,650	1546	930	1933	1274	3206	2,301,125
	Cattle female: 1-2 years	862,750	1221	573	1526	785	2311	1,993,972
	Cattle male: under 1 year	721,200	533	495	666	678	1344	969,532
	Cattle female: under 1 year	700,050	556	477	695	653	1348	943,965
	Sheep							
	Ewes: lowland & upland	2,412,500	584	65	730	89	819	1,975,937
	Other sheep > 1 year	109,800	526	59	657	80	737	80,938

(**Table 2** Continued)

Scenario	Animal category	Animal numbers	Grass intake[1] (kg DM/head)	Silage intake (kg DM/head)	Grass requirement[2] (kg DM/head)	Silage requirement[3] (kg DM/head)	Total requirement[4] (kg DM/head)	Annual grass requirement[5] (t DM)
	Rams	72,400	526	59	657	80	737	53,369
	Other sheep (mainly lambs)	2,425,500	204	23	255	32	287	694,922
							Total	**21,963,933**

[1]kg DM/head = kg dry matter per head.
[2]Grass requirement = grass intake revised based on a herbage utilisation rate for cattle of 0.60 kg DM ingested by livestock per kg DM grown for cattle for Scenarios 1, 2 and 5 and 0.80 kg DM ingested by livestock per kg DM grown for Scenarios 3, 4 and 6, respectively. A grass utilisation rate of 0.80 kg DM ingested by livestock per kg DM grown is assumed for sheep in all scenarios.
[3]Silage requirement = silage intake revised based on a silage utilisation rate of 0.73 kg silage DM per kg DM grass grown.
[4]Total requirement = grass requirement + silage requirement. It is assumed that concentrate DM intake requirements outlined by O'Mara (2006) continue to be fed to each cattle group.
[5]Annual grassland requirement = (total requirement * animal number).

4.8 to 6.0 (0.76 kg grass DM ingested by livestock per kg grass DM grown) t DM/ha, respectively. This may ultimately lead to an increase in grass utilisation rates, a decrease in grassland requirement and an increase in the grassland resource available for alternative applications. This decrease in total grassland requirement does not suggest that grass and grass silage DM intake requirements decrease, but that the overall requirement for 'grassland area' decreases as the efficiency of grass utilisation increases.

Achievement of the targets of 'Food Harvest 2020' (DAFF 2010) for the dairy and beef sectors is likely to result in changes in the size and composition of the national cattle herd, with an increase in the proportion of dairy cows and a subsequent decline in suckler cow numbers (Table 2) (Donnellan and Hanrahan 2011). An average annual grassland resource of 0.39 million t DM in excess of livestock requirements, was observed following implementation of 'Food Harvest 2020' in Scenario 5. This reflects the large increase in the share of dairy cows in the national herd compared with current numbers (Table 2). This suggests that following implementation of 'Food Harvest 2020', under current grassland management and production practices, only a relatively small proportion of the grassland biomass resource would be available for alternative uses. However, the increased intensity of dairy production under 'Food Harvest 2020' is also likely to result in an increase in N fertiliser use (Donnellan and Hanrahan 2011). If 'Food Harvest 2020' implementation was accompanied by increasing N fertiliser input and an increase in the grass utilisation rate of cattle (0.80 kg grass DM ingested by livestock per kg grass DM grown; Scenario 6) there would likely be a substantial increase

Table 3. Annual available grassland resource in excess of livestock requirements

Scenario	Grass supply (t DM)	Grass requirement (t DM)	Available grassland resource [1] (t DM)
1	26,548,787	24,879,139	1,669,648
2	34,167,732	24,879,139	9,288,594
3	26,548,787	20,931,099	5,617,688
4	34,167,732	20,931,099	13,236,634
5	26,548,787	26,154,480	394,306
6	34,167,732	21,963,933	12,203,800

[1]Available grassland resource = grass supply – grass requirement.

in grass supply and a decrease in grass requirement. This has the potential to increase the average annual available grassland resource to 12.2 million t DM

This study suggests that there is a current average annual grassland resource of *ca.* 1.7 million t DM available for alternative uses, and that there is significant potential to increase this resource, even allowing for the implementation of the ambitious targets of 'Food Harvest 2020' (up to 12.2 million t DM/annum). Although outside the scope of this study, future work should focus on determining the relative geographical and seasonal distribution of this resource. This will provide commercially useful information on the regional potential and potential size of grass based anaerobic digestion and green biorefining industries.

However, it could be postulated that the potential availability of this 'surplus' grassland resource would be highest in areas that have experienced declining livestock numbers and in areas with relatively low stocking rates. The movement of livestock from areas with low stocking rates to areas with moderate stocking rates could potentially release land and concentrate the relative geographical distribution of this resource.

Similarly, it could be postulated that a large proportion of this grassland resource would be available during the primary growth (i.e. May, June and July) and as with current silage and hay production practices this would represent a narrow window in which to capture this resource. Furthermore, the magnitude of this grassland resource may vary from year to year, as there is considerable variation in grass growth within and between years. This can be largely attributed to the variation in climatic factors that influence plant growth. For example, annual (2003 to 2011 inclusive) grass DM yields varied from 12.74 to 14.96 t DM/ha in the Department of Agriculture, Food and the Marine feed crop variety trials (intermediate and late varieties, 2nd year harvest yields; DAFM 2012). These trials are conducted annually under consistent management procedures at five locations throughout Ireland: Leixlip, Co. Kildare; Fermoy, Co. Cork; Raphoe, Co. Donegal; Athenry, Co. Galway and Piltown, Co. Kilkenny. Applying this year-to-year variation (i.e. mean = 13.81 t DM/ha/annum; standard deviation = 0.777; coefficient of variation = 0.056) to the annual grass supply data in Scenario 1 would suggest that annual grass supply could vary from 23.6 to 28.0 million t DM (i.e. two standard deviations). This suggests that in some years there may be no overall national surplus grassland resource available, but that in years where good DM yields are achieved there is a potential to build up large grass silage feedstock reserves.

Conclusions

This study suggests that under current grassland management and production practices, and present livestock numbers, there is an average annual grassland resource of *ca.* 1.7 million t DM available in excess of livestock requirements. Furthermore, changes to current grassland management and production practises have the potential to significantly increase this resource to *ca.* 13.2 million t DM/annum (or 12.2 million t DM/annum following implementation of 'Food Harvest 2020'). In these instances alternative applications such as anaerobic digestion and green biorefining would not have to compete with traditional agricultural production systems, but could provide a potential additional enterprise and income to farmers.

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