Farm Carbon Toolkit

Integrating biomass crop cultivation into arable and livestock farming

Data assumptions behind the carbon emissions calculations for the Envirocrops platform.

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Purpose

Farm Carbon Toolkit have constructed a set of farm models to compare GHG emissions from arable and livestock farming with biomass crop cultivation. FCT established a set of assumptions for typical arable, livestock and biomass farming on agricultural land in the UK and Ireland, which will be used to calculate GHG emissions. Using the Envirocrops platform, farmers in the UK and Ireland will be able to compare GHG emissions and any potential GHG reductions when considering switching part of their land into biomass crop cultivation. This document outlines the underlying assumptions of the data that was used in the carbon emissions calculations.

Arable Rotations Assumptions

Two arable rotation baselines were modelled, a three and a five year rotation. For the biomass crop hemp, these rotations were modelled with hemp as an annual crop within the rotation. The assumptions for rotations emissions are to farm gate. All rotations were modelled on a 100 hectare (ha) area, data is then converted into per ha values and extrapolated to 20 years for comparison with biomass crop cultivation.

Three Year Arable Rotation

A three year arable rotation consisting of winter wheat, spring barley and oilseed rape (OSR) was modelled based on a 100 ha area (wheat = 34 ha, barley = 33 ha, OSR = 33 ha).

Average UK crop yield and recommended fertiliser rates were taken from the Nix Farm Management Pocketbook, (55th Edition[1]), see Table 1. For wheat and OSR, we assume N is applied three times throughout the growth season in the form of 34.5% Ammonium Nitrate, P is applied once in the form of 48% Triple super phosphate and K is applied once in the form of 60% Muriate of potash. For barley, one application each of N, P and K is assumed. The required tonnes of N, P and K products were calculated for the area of the crop and all fertilisers are assumed to be of EU origin.

The quantity and spraying regime for herbicides, fungicides, molluscicides, insecticides and growth regulators was based on suggestions from FCT expert farm advisors'. For winter wheat, herbicides, fungicides and molluscicides were sprayed twice. An average of 2.5 sprays (between 2 - 3 sprays) for spraying wheat with insecticides was used. For spring barley, herbicides were sprayed twice and fungicides once. For OSR, we assumed four applications of herbicide, three applications of fungicides, two of molluscicides and one insecticide. For each crop only one application of growth regulators were assumed. Water usage for the sprays was assumed to be at 100 Litres per ha per spray for herbicides, fungicides, molluscicides, insecticides and 220 Litres per ha for growth regulators.

Manual operations involved in cultivating the different crops was used to estimate red diesel fuel usage and are provided in Table 1. The assumptions for red diesel fuel usage per operation are as per methodology version 3.1 of the farm carbon calculator (data from reference 37 of the farm carbon calculator) and remain constant throughout. Expected yields were multiplied by the area under cultivation and the default option on the farm carbon calculator for residue management was chosen (50% residues removed from the field) for each crop.

Table 1. Summary of the three year arable rotation containing annual values.

Variable	Winter Wheat	Spring Barley	Oilseed rape
Area (ha)	34	33	33
Yields (t/ha)	8.3	5.75	3.5
Fertilisers			
• kgN/ha (34.5% AN)	190	70	160
• kgP/ha (48% P)	58	49	49
• kgK/ha (60% K)	87	69	39
Sprays			
• Herbicide (kgAI/ha)	1.323	0.15	1.35
• Fungicide (kgAI/ha)	0.57	0.69	0.77

• Molluscicide (kgAI/ha)	0.242	n/a	0.6
• Insecticide (kgAI/ha)	0.013	n/a	0.0075
• Growth regulator (kgAI/ha)	1.1	0.75	1.1
Field operations			
• Mouldboard ploughing	1 pass	1 pass	n/a
• Stubble cultivations	n/a	n/a	1 pass
• Rolling	1 pass	1 pass	1 pass
• Power harrowing	n/a	1 pass	n/a
• Power harrow drilling	1 pass	n/a	n/a
• Flat lift rape drilling	n/a	n/a	1 pass
• Conventional drilling	n/a	1 pass	n/a
• Combining	1 pass	1 pass	1 pass
• Straw chopping	n/a	1 pass	n/a
• Fertiliser spreading	5 passes	3 passes	5 passes
• Spraying	8.5 passes	4 passes	12 passes
Water			
Total mains water usage (m^3)	36.38	17.16	47.52

Five year arable rotation

A five year arable rotation consisting of winter wheat, spring barley, OSR and field beans was modelled for a 100 ha area, with wheat grown twice in the rotation (wheat = 40 ha, barley = 20 ha, OSR = 20 ha, field beans = 20 ha).

Assumptions for wheat, barley and OSR remained the same and were only adjusted for the new area (20 ha). For field beans, only one application P and K fertiliser, herbicide and fungicide each was assumed with quantities and operations provided in Table 2.

Table 2. Summary of five year arable rotation containing annual values. Grey values are the same as provided in table 1.

Variable	Winter Wheat	Spring Barley	Oilseed rape	Field Beans
Area (ha)	40	20	20	20
Yields (t/ha)	8.3	5.75	3.5	4.3
Fertilisers				
• kgN/ha (34.5% AN)	190	70	160	0
• kgP/ha (48% P)	58	49	49	47
• kgK/ha (60% K)	87	69	39	52
Sprays				
• Herbicide (kgAI/ha)	1.323	0.15	1.35	1.07
• Fungicide (kgAI/ha)	0.57	0.69	0.77	0.25
• Molluscicide (kgAI/ha)	0.242	n/a	0.6	n/a
• Insecticide (kgAI/ha)	0.013	n/a	0.0075	n/a
• Growth regulator (kgAI/ha)	1.1	0.75	1.1	n/a
Field operations				
• Mouldboard ploughing	1 pass	1 pass	n/a	1 pass
• Stubble cultivations	n/a	n/a	1 pass	n/a
• Rolling	1 pass	1 pass	1 pass	1 pass
• Power harrowing	n/a	1 pass	n/a	1 pass
• Power harrow drilling	1 pass	n/a	n/a	n/a

• Flat lift rape drilling	n/a	n/a	1 pass	n/a
• Conventional drilling	n/a	1 pass	n/a	1 pass
• Combining	1 pass	1 pass	1 pass	1 pass
• Straw chopping	n/a	1 pass	n/a	1 pass
• Fertiliser spreading	5 passes	3 passes	5 passes	2 passes
• Spraying	8.5 passes	4 passes	12 passes	2 passes
Water				
Total mains water usage (m^3)	42.8	10.4	28.8	4

Arable Rotations with Hemp

Hemp is an annual biomass crop, therefore it was swapped into the three year and five year arable rotations models in place of OSR, as it is typically treated as a break crop.

Data for average UK hemp yields and fertiliser regime was extracted from the Envirocrops website[2]. For hemp, we assume N is applied twice as a split application (70% at planting and 30% at elongation/rapid growth phase[2]) in the form of 34.5% Ammonium Nitrate. We assume P is applied once in the form of 48% Triple super phosphate and K is applied once in the form of 60% Muriate of potash. The required tonnes of N, P and K products were calculated for the area of the crop and all fertilisers are assumed to be of EU origin.

Herbicide application for hemp was assumed to be at the same rate for wheat but with only one pass for spraying. No other fungicides, insecticides, molluscicides or growth regulators are necessary. Expected yields were multiplied by the area under cultivation. The hemp emissions factor on the carbon calculator assumes annual renewal of belowground material and 90% of residues removed at harvest (v3.1 of the carbon calculator methodology), due to the nature of removing the wholecrop for the biomass market.

As per previous methods, values were multiplied by the area for each crop, summed to give totals for the rotation and then divided by the total area (100 ha) to get per ha quantities. Per ha values were extrapolated to a 20 year scale.

Table 3. Summary of hemp assumptions made for three and five year rotations containing annual values.

Variable	Hemp 3 year	Hemp 5 year
Area (ha)	33	20
Yields (t/ha)	7.5	7.5
Fertilisers		
• kgN/ha (34.5% AN)	110	110
• kgP/ha (48% P)	80	80
• kgK/ha (60% K)	140	140
Sprays		
• Herbicide (kgAI/ha)	1.323	1.323
• Fungicide (kgAI/ha)	n/a	n/a
• Molluscicide (kgAI/ha)	n/a	n/a
• Insecticide (kgAI/ha)	n/a	n/a
• Growth regulator (kgAI/ha)	n/a	n/a
Field operations		
• Mouldboard ploughing	1 pass	1 pass
• Rolling	1 pass	1 pass
• Power harrowing	1 pass	1 pass
• Cultivator drill (combi-drilling)	1 pass	1 pass
• Forage harvester	1 pass	1 pass
• Spraying	1 pass	1 pass

• Fertiliser spreading	4 passes	4 passes
Water		
Total mains water usage (m^3)	3.3	2

Livestock Assumptions

Six grazing livestock farms were modelled. All scenarios assume livestock are grazing outside for 100% of the year and are modelled on a 100 ha area. The assumptions for livestock emissions are to farm gate. These values are then converted to per ha (Table 4) and extrapolated for 20 years for comparison with biomass crop cultivation.

For all livestock scenarios, red diesel fuel usage was estimated based on the assumption that beef cattle require 45.31 L/ head and Ewes require 1.89 L/ head. This includes all tractoring time associated with grazing livestock and was extracted from a report to Defra (2007) by the University of Warwick and FEC Services Ltd[3]. To convert between kWh to red diesel litres we assumed a conversion rate of 10 kWh to 1 L red diesel.

Total livestock for each farming scenario was assigned by taking the stock capacity - grazing livestock units (GLU)/ ha - for each pasture type[1], multiplying by the area (100 ha), then dividing by the GLU value for beef cows (excluding calves = 0.75[1]) or sheep (other sheep, over 1 year = 0.08[1]).

For the scenarios with fertiliser inputs, we assume N is applied in the form of 34.5% Ammonium Nitrate, P in the form of 48% Triple super phosphate and K is applied in the form of 60% Muriate of potash. The required tonnes of N, P and K products were calculated for the area and all fertilisers are assumed to be of EU origin.

Beef cattle grazing assumptions

Varying levels of inputs and intensity of grazing cattle systems were modelled (Table 4). The same GLU/ha value for the no and low input scenario was assumed (0.9) and aligns with the stocking capacity recommended for low input permanent pasture systems[1]. These two scenarios were chosen so that farmers have the option of including fertilisers or not, with the same number of cattle, in the emissions comparisons with biomass cultivation. For the high input grazing system, the GLU/ ha and fertiliser requirements are associated with improved permanent pasture[1] and for the high input silage scenario, the GLU/ ha and fertiliser recommendations are associated with a long term ley (*e.g.* 7 year) with a forage yield of 40 t/ha[1]. The high input silage scenario includes taking a cash crop off the land and the associated crop residue emissions.

Beef fattening heifers were chosen as the category of beef cow, using the carbon calculator default values for dry matter intake and liveweight, with 100% of manure handled as in field manure (v3.1).

Sheep grazing assumptions

Low and no fertiliser input sheep grazing systems were modelled utilising the same stock capacity for low input permanent pasture[1] and fertiliser inputs as the low input cattle grazing scenario. Ewes were chosen as the livestock entered into the calculator using default settings for dry matter intake and liveweight, with 100% of manure handled as in field manure (v3.1).

Table 4. Livestock farm scenarios, annual values per ha.

Variable	No input cattle grazing	Low input cattle grazing	High input cattle grazing	High input cattle silage	Low input sheep grazing	No input sheep grazing
Stock capacity (GLU / ha)	0.9	0.9	1.2	1.5	0.9	0.9
Fuel (L/ ha)	54.37	54.37	72.50	90.62	21.26	21.26
Livestock						
Beef- Fattening heifers (Head/ ha)	1.2	1.2	1.6	2.0	n/a	n/a
Sheep - Ewes (Head/ ha)	n/a	n/a	n/a	n/a	11.25	11.25
Fertilisers						

KgN/ha (34.5% AN)	n/a	50	100	150	50	n/a
kgP/ha (48% P)	n/a	18	22	28	18	n/a
kgK/ha (60% K)	n/a	60	77	96	60	n/a
Silage / Hay						
Non - legume hay (t/ha)	n/a	n/a	n/a	40	n/a	n/a

Biomass Crop Assumptions

Biomass crops were modelled on a per ha basis over a 20 year period for conversion from arable land (Table 5) and conversion from grassland (Table 6). The assumptions for biomass emissions are to farm gate. All biomass crops presented here are assumed to require no fertiliser inputs as per expert advice from Envirocrops advisors.

Switchgrass and Reed Canary Grass

The lifespan of switchgrass and reed canary grass is around 10 years, therefore these systems were modelled as planting twice within the 20 year period. The crop is then harvested annually, however 16 harvests were chosen within this time frame based on the assumption that the crop takes 2 - 4 years to reach maximum yields[2]. Therefore, the operations associated with planting the crop is twice within a 20 year period, whilst the harvesting operations, such as mowing and bailing occur 16 times.

Pre-planting herbicide spraying is not assumed for the conversion from arable land, but is necessary from converted grassland for these crops[2]. All scenarios include the herbicide recommendation for post crop spraying to return the land after biomass cultivation.

Expected yields for each crop were multiplied by the number of harvests. The switchgrass and reed canary grass factor in the calculator assumes a 10 year root stock renewal and that 90% of crop residues are removed at harvest (v3.1).

Miscanthus

The lifespan of miscanthus is assumed to be 20 years and the first harvest is assumed to occur in year three after its yield building phase. This crop is then harvested annually, therefore 17 harvests were modelled. Miscanthus can be planted with a potato planter, therefore the fuel usage assumption for this machinery was utilised. Mowing and bailing was chosen as the harvesting method.

Pre-planting herbicide spraying is not assumed for miscanthus, but the herbicide recommendation for post crop spraying to return the land after miscanthus cultivation is included.

Expected yields for each crop were multiplied by the number of harvests. The miscanthus factor in the calculator assumes a 20 year root stock renewal and that 90% of crop residues are removed at harvest (v3.1).

SRC Willow and SRC poplar

We assumed a 20 year lifespan for short rotation willow and poplar with 6 harvests as these crops are typically harvested every three years. SRC willow and poplar can be planted with a step planter[2], the fuel usage for this operation was assumed to be the same as a potato planter. A forage harvester was chosen as the harvesting operation for fuel consumption estimation.

Pre-planting herbicide spraying is necessary for SRC willow and poplar on arable (5L/ ha)[2] and grassland (7L/ ha)[2]. Herbicide spraying to return the land post crop is included.

Expected yields for each crop were multiplied by the number of harvests. The SRC willow and SRC poplar emissions factors in the calculator assumes a 20 year root stock renewal and that 70% of crop residues are removed at harvest, as despite most of the above-ground plant being removed every harvest, there is leaf litter associated with the crop during the growth period and harvest that is returned to the soil (v3.1).

Table 5. Biomass crop farming scenarios from converted arable land

Conversion from arable land					
Variable	**Switchgrass**	**Reed Canary Grass**	**Miscanthus**	**SRC Willow**	**SRC Poplar**
Lifespan (yrs)	10	10	20	20	20
Harvests in 20 year period	16 (8 harvests x 2)	16 (8 harvests x 2)	17	6	6
Yield (t/ha)	10.15	6	12	12	12
Field operations					
Mouldboard Ploughing	2 passes	2 passes	1 pass	1 pass	1 pass
Rolling	2 passes	2 passes	1 pass	1 pass	1 pass
Potato planter	n/a	n/a	1 pass	n/a	n/a
Step planter	n/a	n/a	n/a	1 pass	1 pass
Conventional drilling	2 passes	2 passes	n/a	n/a	n/a
Forage Harvester	n/a	n/a	n/a	6 passes	6 passes
Mower	16 passes	16 passes	17 passes	n/a	n/a
Baler	16 passes	16 passes	17 passes	n/a	n/a
Spraying	2 passes	2 passes	1 pass	2 passes	2 passes
Sprays					
Herbicide (kgAI/ha)	1.8	1.8	1.8	3.6	3.6

Table 6. Biomass crop farming scenarios from converted grassland

Conversion from grassland					
Variable	**Switchgrass**	**Reed Canary Grass**	**Miscanthus**	**SRC Willow**	**SRC Poplar**
Lifespan	10	10	20	20	20
Harvests in 20 year period	16 (8 harvests x 2)	16 (8 harvests x 2)	17	6	6
Yield (t/ha)	10.15	6	12	12	12
Field operations					
Sub-soiling	n/a	n/a	n/a	1 pass	1 pass
Flat lift Ploughing	2 passes	2 passes	1 pass	1 pass	1 pass
Rolling	2 passes	2 passes	1 pass	1 pass	1 pass
Potato planter	n/a	n/a	1 pass	n/a	n/a
Step planter	n/a	n/a	n/a	1 pass	1 pass
Conventional drilling	1 pass	1 pass	n/a	n/a	n/a
Forage Harvester	n/a	n/a	n/a	6 passes	6 passes
Mower	16 passes	16 passes	17 passes	n/a	n/a
Baler	16 passes	16 passes	17 passes	n/a	n/a
Spraying	3 passes	3 passes	1 pass	2 passes	2 passes
Sprays					
Herbicide (kgAI/ha)	3.6	3.6	1.8	4.32	4.32

Scenario codes

Table 7. A table containing the scenario codes and titles for the calculator API.

Scenario	Code	Title
Three year arable rotation	A_3	arable_3yr_baseline
Five year arable rotation	A_5	arable_5yr_baseline
Three year arable with hemp	A_3_H	arable_3yr_hemp
Five year arable with hemp	A_5_H	arable_5yr_hemp
No input cattle grazing	L_N_C	livestock_no_input_cattle
Low input cattle grazing	L_L_C	livestock_low_input_cattle
High input cattle grazing	L_H_C	livestock_high_input_cattle
High input cattle silage	L_H_S_C	livestock_high_input_silage_cattle
No input sheep grazing	L_N_S	livestock_no_input_sheep
Low input sheep grazing	L_L_S	livestock_low_input_sheep
Miscanthus onto arable land	B_Mi_A	biomass_miscanthus_arable
Switchgrass onto arable land	B_Sw_A	biomass_switchgrass_arable
Reed canary onto arable land	B_Rc_A	biomass_reedcanary_arable
SRC willow onto arable land	B_SRCW_A	biomass_SRC_willow_arable
SRC poplar onto arable land	B_SRCP_A	biomass_SRC_poplar_arable
Miscanthus onto grassland	B_Mi_G	biomass_miscanthus_grassland
Switchgrass onto grassland	B_Sw_G	biomass_switchgrass_grassland
Reed canary grass onto grassland	B_Rc_G	biomass_reedcanary_grassland

SRC willow onto grassland	B_SRCW_G	biomass_SRC_willow_grassland
SRC poplar onto grassland	B_SRCP_G	biomass_SRC_poplar_grassland

Data sources

Data for arable yields, fertiliser rates, grazing livestock units and forage production systems were provided in John Nix Farm Management Pocketbook, 55th Edition[1]. Data on sprays active ingredients, number of applications and operations for arable rotations were provided by FCT's expert farm advisors. Data for grazing livestock fuel use assumptions was extracted from a DEFRA funded report (AC0401)[3]. Data on biomass crops yields and management practices was provided by the Envirocrops website[2] from the different crops best practice guidelines webpages and expert biomass crop advisors.

Disclaimer

References

1. Redman, G. (2024) *John Nix Pocketbook: For farm management*. 55th edn. S.l.: AGRO BUSINESS CONSULTANTS.
2. *Envirocrops*. (2024) Available at: https://envirocrops.com/ (Accessed: 20 December 2024).
3. Warwick, H.R.I. (2007) AC0401: Direct energy use in agriculture: opportunities for reducing fossil fuel inputs. *University of Warwick, Warwick*. Available at: https://ukerc.rl.ac.uk/pdf/AC0401_Final.pdf