Supplementary material: DESTiny, an Online Farm-Wide Tool to Estimate the Net Carbon Emissions of a Pasture-Based Dairy Farm in South Africa

Sub-model 1: Supplementary material S-1a: Farm input data required for the below-ground and other farm input related to direct emissions

Variable	Value/ Unit	Description
Soil type and C content	The area in ha and C% from soil analysis are needed for the applicable soil types.	Information from soil analysis are needed, C% and soil type. Soil type options are: Sand, Sandy loam, Loam, Clay loam, slit loam and Clay soils
ASN - Ammonium sulphate nitrate	kg per ha year	21% N
Calcium nitrate	kg per ha year	16% N
LAN -Limestone ammonium nitrate	kg per ha year	27% N
Potassium nitrate	kg per ha year	13% N
UAN- urea ammonium nitrate	kg per ha year	32% N
Urea	kg per ha year	46% N
Organic fertiliser	kg per ha year	15% N
Compost	kg per ha year	2% N
Other N fertiliser	kg per ha year	For any other fertiliser types not in the given list, the N content can be inserted
Dairy chemicals	kg year^{-1}	The total kg dairy chemicals used per year
Diesel consumption	Liter year^{-1}	Total liters of diesel used per year
Electricity usage	Kwh year^{-1}	Total electricity usage per year for irrigation and the dairy
Electricity from renewable energy sources	Kwh year^{-1}	Electricity usage from renewable energy
Herbicide usage	Kg year^{-1}	Total herbicide usage per year
Insecticide usage	Kg year^{-1}	Total insecticide usage per year
Pesticides	kg year^{-1}	Total pesticide usage per year
Seed planted	Kg year^{-1}	Total seed planted per year
Irrigation	Ha year^{-1}	Total irrigated ha per year
Medical, vet and AI	Rand per year	Rand value per year is needed to calculate profitability
Medical, vet and AI		
Other variable costs		
Labour cost		
Land rented total cost		
Other fixed cost		

Sub-model 1: Supplementary material S-1b: Constants and assumptions for the belowground and other farm input related to direct emissions

Variable	Value/ Unit	Description	Reference
Clay bulk density	1.35 tonne/m^3	Sandy soils have the highest bulk densities, while clay and organic matter-rich soils have the lowest. Maintaining optimal bulk density is important for soil health and plant growth.	Zeri et al. (2018)
Clay loam density	1.45 tonne/m^3		
Loam bulk density	1.5 tonne/m^3		
Sand bulk density	1.65 tonne/m^3		
Sandy loam bulk density	1.55 tonne/m^3		
Silt loam bulk density	1.5 tonne/m^3		
Incecticides EF	6.3 kg CO_2eq/kg		Wang et al. (2015)
Herbicides EF	5.1 kg CO_2eq/kg		
Fungicides and bactericides EF	5.1 kg CO_2eq/kg		
Seed EF	1.22 kg CO_2eq/kg		
Intensive tillage	0.5 kg CO_2eq/ha	The different emission factors for different tillage practices	Chen et al. (2022), NRCS (2023)
Reduced tillage	0.3 kg CO_2eq/ha		
Mulch tillage	0.2 kg CO_2eq/ha		
Ridge tillage	0.4 kg CO_2eq/ha		
Strip tillage	0.3 kg CO_2eq/ha		
No till	0.1 kg CO_2eq/ha		
SA emission factor for N fertiliser	kg N_2O/ha	N2O emissions (kg /ha) = 1.99 + 1.39 × exp(0.00488) * N - balance (kg N/ha)	Smit et al. (2020)
N fertiliser manufacturing	Kg CO_2eq/kg	0.06	FAO (2019)
Grass seeds	Kg CO_2eq/kg	1.22	
P fertiliser	Kg CO_2eq/kg	1.35	Wang et al. (2015)
Electricity emission factor	Kg CO_2/kwh	1.06	Eskom (2022)
Diesel emission factor	kg CO_2/L	2.677	Defra (2020)
Emission factor for N fertiliser production	kg CO_2/kg nutrient	0.61	Wood & Cowie (2004)
Emission factor - dairy chemicals	g CO_2/kg	0.1	Hagemann et al. (2012)
GWP CH_4	CO_2eq	28	IPCC (2019)
GWP N_2O	CO_2eq	265	

Sub-model 2: Supplementary material S-2a: Required farm data for the aboveground sub-model

Variable	Value/ Unit	Description
Ryegrass Kikuyu Mixed pasture, predominantly grass species Mixed pasture with more than 40% legumes Mixed pasture with more than 40% forage herbs	Area in ha Yield in kg/ha % Allocation to different animal groups Rotations/ year	Pasture input exist for irrigated and dryland pasture. Depending on the type of pasture planted, the required information should be entered in the DESTiny.
Maize or other crop Silage Lucerne bales Hay bales	Area in ha Yield in kg/ha % Allocation to different animal groups Rotations/ year	Input for Crop and Fodder production, depending on what was planted, the information should be entered in this section.

Sub-model 2: Supplementary material S-2b(1): Constants and assumptions for the aboveground sub-model

Pasture type	CP %	NDF%	NDFD%	ADF%	FA%	ME (MJ/kg)
Ryegrass	22	45	70	27	2.5	10.8
Kikuyu	15	65	65	33	2.2	9.01
Mixed pasture (mostly grass)	23	55	64	28	2.3	10.2
Mixed pasture (> 40 % legume)	23	48	61	28	2.4	10.4
Mixed pasture (> 40 % forage herb)	22	48	74	25	2.2	10.6

Average nutrient fractions in different pasture types (Ammann et al. 2023, Van der Kolf. 2010), Where CP is crude protein as % of DM; NDF is neutral deterrent fibre as % of DM, NDFD is NDF digestibility; ADF is acid detergent fibre as % of DM, FA is fatty acid as % of DM and ME is metabolisable energy per kg DM

Sub-model 2: Supplementary material S-2b(2): Constants used in the aboveground sub-model to calculate C capture in pastures

Variable	Value/ Unit	Description	Reference
N-fixation factor	0.0026	N fraction fixated	Teixiera et al. 2019
C fraction in grass pasture	0.03	C fraction	IPCC (2006)
C fraction in legume pasture	0.04	C fraction	
Respiration rate	0.05	C lost due to respiration	
N in pasture	6.25*protein in pasture	CP % *6.25	CP multiplied by default factor to calculate N from CP

Sub-model 3: Supplementary material S-3a: Required farm data for the animal sub-model

Variable	Value/Unit	Description
Opening stock: number of mature cows	Cows/year	Number of mature cows at the beginning of the year that is entered in DESTiny
Number of cows per acquisition	Cows/year	Number of cows acquired for the farm
Maximum number of productive stock	Cows/year	Maximum stock for that year
Productive stock net fertility rate	%	Number of cows and heifers pregnant from total available cows and heifers
Retained female calves	%	% female calves kept for replacement or growth
Fraction of bullocks born	%	% bull calves born
Female calves: mortalities	calves/year	All female calf mortalities
Bull calves: mortalities - current	calves/year	All bull calf mortalities
Average weight - calves	Kg	Weight at birth
Average weight - heifers	Kg	Weight at 12 months
Average weight - cow mature body weight	Kg	Mature cow weight
Milk Fat - ave per year	%	Average milk fat % over the year
Milk protein - ave per year	%	Average protein % over the year
Milk per cow per day (lit)	liter/cow/day	Average milk production for the year in liter per cow per day

Sub-model 3: Supplementary material S-3b(1): Constants and assumptions for the animal sub-model

Variable	Value/ Unit	Description	Reference
CH4 (enteric)	(13.6×DM intake+3.43×NDF content +33.2)×55.65/1 000	MJ day^{-1}	Dong et al. (2022)
DMI		Kg day^{-1}	
NDF		% of DM	
Lactating cow enteric CH4	-126 + 11.3 × DMI + 2.30 × NDF + 28.8 × MF + 0.148 × BW	$gday^{-1}$	Niu et al. (2018)
Heifers and dry cows	$((GE \times (Y_m/100)) \times 365))/55.65$	Kg $year^{-1}$	IPCC (2019); Eq. 10.21
DMI	*DMI = 12.0-0.107 x fNDF + 8.17 x ADF/NDF + 0.0253 x fNDF – 0.328 x (ADF/NDF – 0.602) x (fNDFD – 48.3) + 0.225 x MY + 00390 x (fNDFD – 48.3) x (MY-33.1)*	Kg day^{-1}	Allen et al. (2019)
fNDF	Forage NDF	% DM	
NDF	Weighted average all feed		
fNDFD	Forage NDF digestibility		
MY	Milk Yield	Kg day^{-1}	
Digestible volatile solids	0.334 DMI + 0.029 HC – 0.058 CP		Appuhamy et al. (2018)
(Digestible VS generate CH4)	(HC: NDF – ADF)		
Urine N (cows)	12 + 0.333 NI	$gday^{-1}$	Johnson et al. (2016)
N intake			
Manure N (cows)	20.3 + 0.654 NI	$gday^{-1}$	Johnson et al. (2016)
Urine N (heifers)	14.3 + 0.51 NI	$gday^{-1}$	
Manure N (heifers)	15.1 + 0.828 NI	$gday^{-1}$	

Enteric CH4 Reduction in lactating cows	-20.4 – (0.911 × nitrate dose) + (0.691 × DMI)	%	Feng & Kebreab (2020)
Reduction in heifers	-10.1 – (0.911 × nitrate dose) + (0.691 × DMI)	%	
Emission factor for concentrate bought	g CO2/kg	22	Hagemann et al. (2012)
Reduction in lactating cows	-20.4 – (0.911 × nitrate dose) + (0.691 × DMI)	%	Feng & Kebreab (2020)
Reduction in heifers	-10.1 – (0.911 × nitrate dose) + (0.691 × DMI)	%	
Methane conversion factor constant	MJ year^{-1}	3.23x365	IPCC (2006)
Methane conversion factor coefficient	MJ year^{-1}	0.809	IPCC (2006)
Energy content of methane	MJ kg^{-1}	55.65	IPCC (2006)

Sub-model 3: Supplementary material S-3b(2): Typical feed fractions in concentrates for cows

Nutrient fraction	Concentrate mix 1	Concentrate mix 2	Concentrate mix 3	Concentrate mix 4	Concentrate mix 5	Concentrate mix 6
DM (%)	88	88	88	88	88	88
CP (%)	11.4	13.6	17	19.3	21.6	17
NDF (%)	17	17	23	23	23	25
NDFD (%)	78	78	80	80	80	80
ADF (%)	6	6	9	9	9	10
FA (%)	4	4	4	4	4	4
ME (MJ kg^{-1})	12.2	12.2	12	12	12	11.7

Where DM is dry matter; CP is crude protein as % of DM; NDF is neutral deterrent fibre as % of DM, ADF is acid detergent fibre as % of DM, FA is fatty acid as % of DM and ME is metabolisable energy per kg DM

Sub-model 3: Supplementary material S-3b(3): Different manure management systems included in the DESTiny tool, as described by the IPCC (2019)

Manure system	Description
Biodigester	Animal excreta with or without straw are collected and aerobically digested in a large containment vessel or covered lagoon. Digesters are designed and operated for waste stabilisation by the microbial reduction of complex organic compounds to CO_2 and CH_4, which is captured and flared or used as a fuel.
Uncovered anaerobic digester	A type of liquid storage system designed and operated to combine waste stabilisation and storage. Lagoon supernatant is usually used to remove manure from the associated confinement facilities to the lagoon.
Liquid / slurry	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year.
Liquid / slurry with crust	Manure is stored as excreted or with some minimal addition of water in either tanks or earthen ponds outside the animal housing, usually for periods less than one year. With liquid manure storage either a natural crust can form or an artificial crust from straw or other material can be created.
Solid storage	The storage of manure, typically for a period of several months, in unconfined piles or stacks. Manure able to be stacked due to the presence of a sufficient amount of bedding material or loss of moisture by evaporation.
Daily spread	Manure is routinely removed from a confinement facility and is applied to cropland or pasture within 24 hours of excretion.
Pasture	The manure from pasture and grazing animals can lie as deposited and is not managed.
Other	For example, burn for fuel, the dung and urine are excreted on fields and dried dung burned for fuel. Manure treated as compost.

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