sustainability

MDPI

1 **Supplementary Materials:**

Table S1: Information collected during the survey about farm characteristics and management

Variable	Description	Unit	Standardization
Age of farmer		years	
Municipality			
Herd size and composition			
Cows	Suckling cows	Number	Livestock Unit (LU) = 1
Bulls		Number	Livestock Unit (LU)= 1
Calves before weaning (male and female)	Calves from 0 to 6 months	Number	Livestock Unit (LU)=0.6
Calves for fattening (male and female)	Calves from 6 to 12 months	Number	Livestock Unit (LU)=0.6
Heifers at the first year	Heifers from 12 to 24months	Number	Livestock Unit (LU)=0.6
Heifers at the second year	Heifers from 24 to 36 months	Number	Livestock Unit (LU)=0.6
Female calves for replacement		Number	
Season of calving		% for month	
Grazing period		days	
In-house period		days	
Birth weight		kg/head	
Body Weight Initial (BWI)	Body weight at the beginning of the period, for each animals' category	kg/head	
Body Weight Final (BWF)	Body weight at the end of the period, for each animals' category	kg/head	
Body Weight Sold (BWS)	Body weight at the time of sale		

Surface and use			
Highlands	High-altitude pasture, grazed during the summer	ha	
Transition pasture	Pasture located at mid elevation, grazed during the spring and autumn transition to and from highland pastures	ha	
Natural meadows	Meadows that have not been plowed and reseeded in the last 50 years. Production of hay or silage can be associated with early and late grazing	ha	
Seminatural meadows	Meadows that have not been plowed and reseeded in the last 15 years. Production of hay or silage can be associated with early and late grazing		
Temporary crops	Cultivated fields that have been plowed and reseeded in the last 5 years. Crops can be cereals, alfalfa, sorghum etc.		
Productivity of parcels	Production of natural and seminatural meadows and temporary crops. The data given by farmers have been converted in DM	Bale of silage	kg DM/ha
		Bale of hay	
		kg DM	
Organic fertilization	Manure input	kg	kg/ha
Willingness to change the land use	For each parcels, first it was asked whether it was classified as natural, seminatural or temporary crops and then whether, for each parcels classified as natural/seminatural meadows was asked to farmers if they were going to change the land use into temporary crops to produce more	Yes/No	
Irrigation		Yes/No	

Off-farm purchased food	kg

3

Table S2: composition of the diet fed to suckler cows and calves (male and female) (kg DM/head/day). Regarding the calf (male and female) for fattening, a distinction has been made between farms with TMR and farms with a traditional fattening system.

	Mean	**SD**	**Min**	**Max**
Cows				
In-house period, days	201	86	0	259
Hay	7.9	4.5	2.3	13.5
Straw	0.3	0.4	0.0	1.0
Grass silage	2.5	3.5	0.0	7.0
Corn silage	0.0	0.0	0.0	0.1
Alfalfa	0.9	1.3	0.0	3.5
Barley	0.3	0.5	0.0	1.0
Calf for fattening (male and female)				
Fattening period[2], days	217	62	183	213
Farms with TMR[1], N=3				
Feed intake	7.6	0.8	7.0	8.5
Hay	4.6	0.5	4.2	5.1
Barley	3.0	0.3	2.8	3.4
Farms with traditional feeding system, N=5				
Feed intake	7.8	1.3	6.6	10.1
Hay	4.9	0.5	4.0	5.4
Concentrate	2.9	1.2	1.8	5.0

[1] TMR: Total Mixed Ration

[2] The fattening period was calculated after weaning (six months from birth)

1 **Table S3**: equations used to compute the environmental impacts

Variable	Description	Unit	Reference
Nitrogen balance			
N intake	= Feed intake (kg DM/d) x presence (days at pasture/in-house) x crude protein diet content/6.25	kg N/year	Katelaars and Van der Meer (1999)
N retention	=(BW[1] final-BW initial) x retention factors[2]	kg N/year	Katelaars and Van der Meer (1999)
N excretion	=N intake - N retention	kg N/year	Katelaars and Van der Meer (1999)
Net energy (NE) requirement			
NE for maintenance (NE_m)	= (Cfi[3] x $(BW)^{0.75}$) x 4.184	MJ/head/day	IPCC, 2006
NE for activity (NE_a)	= Ca[4] x NEm	MJ/head/day	IPCC, 2006
NE for lactation (NE_l)	= Milk yield (kg/d) x (0.0929 x fat[5] (%) + 0.0547 x protein[6] (%) + 0.192) x 4.184	MJ/head/day	IPCC, 2006

NE for Pregnancy (NE_p)	= 0.45	MJ/head/day	IPCC, 2006
NE requirement	= NE_m+NE_a+NE_l+NE_p	MJ/head/day	IPCC, 2006
Global Warming Potential (GWP)			
Enteric CH_4	= (GEI[7] x (γm[8]/100) x 365) / 55.65	kg CH_4/head/day	IPCC, 2006
Volatile solid excretion rates (VS)	= [GEI[7] x (1 − DE%/100) + (0.02 x GE[9])] x [(1-ASH[10])/18.45]	kg VS/day	IPCC, 2006
CH_4 from manure storage	= (VS x presence (days)) x (Bo(T)[11] x 0.67 x 0.04	kg CH_4/animal/year	IPCC, 2006
Direct N_2O from manure storage	= N excretion in-house (kg/year) x 0.005 x 44/28	kg/year	IPCC, 2006
N volatilized from manure storage (N_{vol_MS})	= N excretion in-house (kg/animal/year)) x 0.26	kg/year	EEA, 2019
Indirect N_2O emissions from manure storage	= (N_{vol_MS} x 0.01) x 44/28	kg /year	IPCC, 2006
N available at fertilized soils (no pasture) (N_{av_s})	= (N excretion in-house − N_{vol_MS} − direct N-N_2O manure storage)	kg/year	

N available at pasture (N_{av_p})	= N excretion at pasture	kg/year		
Direct N_2O emissions from fertilized soils and pasture	= (N_{av_s} x 0.01 + N_{av_p} x 0.02) × 44 / 28	kg /year	IPCC, 2006	
N volatilisation from fertilized soils and pasture (N_{vol_field})	= N_{av_s} x 0.2 + N_{av_p} x 0.2	kg /year	IPCC, 2006	
Indirect N_2O emissions from fertilized soils and pasture	= (N_{vol_field} x 0.01) x 44/28	kg/year	IPCC, 2006	
$CO_{2\text{-eq}}$ from CH_4	= CH_4 * 28	kg/year	IPCC, 2014	
$CO_{2\text{-eq}}$ form N_2O	= N_2O * 265	kg/year	IPCC, 2014	
$CO_{2\text{-eq}}$ straw	= kg straw x 0.58	kg /kg DM	Ecoinvent (2015)	Centre
$CO_{2\text{-eq}}$ alfalfa	= kg alfalfa x 0.27	kg /kg DM	Ecoinvent (2015)	Centre
$CO_{2\text{-eq}}$ silage	= kg silage x 0.17	kg /kg DM	Ecoinvent (2015)	Centre
$CO_{2\text{-eq}}$ barley	= kg barley x 0.38	kg /kg DM	Ecoinvent (2015)	Centre

$CO_{2\text{-eq}}$ hay	= kg hay x 0.3	kg /kg DM	Ecoinvent (2015)	Centre
Acidification potential (AP)				
NH_3 from manure storage	= N_{vol_MS} × 17/14	kg/year	IPCC, 2006	
NH_3 field (kg/year)	= N_{vol_field} × 17/14	kg/year	Guinée et al., 2002	
SO_2-eq from NH_3	= NH_3 × 1.88	kg/year	IPCC, 2006	
SO_2-eq straw	= kg straw × 0.006	kg /year	Ecoinvent (2015)	Centre
SO_2-eq alfalfa	= kg alfalfa x 0.02	kg /year	Ecoinvent (2015)	Centre
SO_2-eq silage	= kg silage x 0.0063	kg /year	Ecoinvent (2015)	Centre
SO_2-eq barley	= kg barley x 0.01	kg /year	Ecoinvent (2015)	Centre
SO_2-eq hay	= kg hay x 0.008	kg /year	Ecoinvent (2015)	Centre
Efficiency production				

Gross energy conversion ratio (ECR)	ECR = GEI (MJ farm/year) / (BWG kg/farm) x 0.59 x 0.81 x 10.67)	Ertl et al., 2015 and Berton et al., 2017
Potentially human edible-gross conversion ratio (HeECR)	HeECR = HeE[12] (MJ farm/year)/ (BWG tot x 0.59 x 0.81 x 10.67)	Ertl et al., 2015 and Berton et al., 2017

[1] BW: Body Weight
[2] 0.025 for suckler cows and heifers, 0.028 for weaned calves for replacement or fattening and 0.032 for pre-weaning calves
[3] Cfi: Coefficient varying for each animal category (0.078 for suckler cows; 0.073 for pre-weaning calves, weaned calves for replacement or fattening and heifers)
[4] Ca: coefficient corresponding to animal feed situation (1 for suckler cows and heifers; 0 for pre-weaning calves, weaned calves for replacement and for fattening)
[6] Fat: 3.46%[6] Protein: 3.34%
[7] GEI: Gross Energy Intake
[8] γm: enteric methane yield based on diet
[9] GE: Gross Energy
[10] ASH: 0.08
[11] Bo(T): maximum methane producing capacity for manure producing capacity for manure produced (m3CH_4/kg VS)
[12] HeE: human edible fraction of animals' diet

13

Table S4: Coefficients of the linear mixed models analyzing log-transformed data of productivity (Kg DM/ha) and manure load (Kg/ha) of parcels with the fixed effects of land use, irrigation, slope and their interaction, the willingness to change land use the random effect of farm.

	Productivity					Manure load				
	DF	Value	SE	T	P	DF	Value	SE	T	P
Intercept	57	8.518	0.394	21.62	<0.001	41	9.341	0.609	15.35	<0.001
Seminatural (SN) vs natural (N)	57	-0.595	0.568	-1.05	0.299	41	0.015	0.380	0.04	0.969
Temporary crop (TC) vs natural	57	-0.508	0.408	-1.24	0.218	41	0.212	0.331	0.64	0.526
Irrigation: yes (IY) vs no (IN)	57	-0.120	0.443	-0.27	0.788	41	0.612	0.312	1.96	0.057
Slope	57	-0.027	0.017	-1.61	0.112	41	-0.003	0.015	-0.19	0.851
Land use change: yes (LCY) vs no (LCN)	57	0.434	0.273	1.59	0.118	41	0.023	0.257	0.09	0.928
SN*IY vs N*IN	57	-0.847	0.815	-1.04	0.303	41	-1.040	0.528	-1.97	0.056
TC*IY vs N*IN	57	-0.024	0.798	-0.03	0.976	41	0.031	0.643	0.05	0.962
Slope: SN vs N	57	0.042	0.044	0.95	0.345	41	0.036	0.031	1.17	0.251
Slope: TC vs N	57	0.054	0.032	1.69	0.097	41	-0.009	0.047	-0.19	0.853