Supplement of Biogeosciences, 11, 4429–4442, 2014
http://www.biogeosciences.net/11/4429/2014/
doi:10.5194/bg-11-4429-2014-supplement

Biogeosciences
Open Access

Supplement of

Assessment on the rates and potentials of soil organic carbon sequestration in agricultural lands in Japan using a process-based model and spatially explicit land-use change inventories – Part 1: Historical trend and validation based on nation-wide soil monitoring

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Supplementary Material A. Method to create inventory of spatially-explicit land-use change in Japan during year 1976-2006.

Grid system

The grid system created in this study has geographical dimensions and coordinate system identical to those in Standard Grid Cell (SGC) system created by former Management and Coordination Agency, the Government of Japan, which has been employed in national statistical surveys in Japan. SGC has four class of layers differs in cell size and its fourth class has same spatial resolution as our grid system created for this study, with spatial resolution of 1/1200 and 1/800 degree (3.0 and 4.5 second), along latitudinal and longitudinal lines, respectively. Size of individual cell of the grid equivalents to a parcel of a square land ca. 100 m on a side, with an area of ca. 10,000 m^2 (1 hectare).

Geographical data sources and interpretation of land-use/land-cover

Brief description on each geographical data sources (with their abbreviated titles in bold) are listed below;

1) **LU**: Land Use Fragmented Mesh Version 1.1 in National Land Numerical Information, created by Ministry of Land, Infrastructure, Transport and Tourism, the Government of Japan. Spatial resolution of 100 x 100 m, along latitudinal and longitudinal lines, respectively. LU map products have been synthesized from various data sources, such as topographical maps, current land usage status maps, satellite images (Landsat, Terra-Aster, ALOS etc.), in combination with several data tables on land-use statistics. Created for fiscal year (FY) 1976, 1987, 1991, 1997, and 2006. From 11 to 16 land-use classifications (paddy field, upland field, orchard, forest, waste area, building use, trunk transportation land, lake, river, etc.) were employed, with the number of classifications differing among some groups of survey periods.

2) **VG**: Vegetation map from Vegetation Naturalness Survey conducted in National Survey on the Natural Environment, created by Ministry of Environment (MOE), the Government of Japan, under authority of Article 4 of the Nature Conservation Law. The VG is a collection set of vector maps with approximately 270 legends of plant communities. Map products created in FY 1983-1986, FY 1989-1993, and FY 1994-1998, compiled in the 3rd, 4th, and 5th survey, respectively, were selected and used in this study. A new nation-wide legend, produced in the 6th survey to unify and arrange locally legends used in predecessor maps, was employed in this study and applied to all predecessor maps by using a legend conversion table provided by MOE.

3) **AL**: Agricultural land map from Basic Survey on Improvement of Agricultural Production Base, created by Ministry of Agriculture, Forestry, and Fisheries (MAFF), the Government of Japan. Vector maps of agricultural fields classified into 4 land-use types (paddy field, upland field, orchard, and grassland). Created in 1992 and 2001. In synthesis of this map product, in some cases, polygons of these types of agricultural fields had been modified so that sum of the area of polygons in each land-use category to be consistent with the agricultural statistics at prefectural level, and thus, may include some bias.

A decision tree was created to decide land-use of each grid cell using legends in LU, VG, and AL as input parameters, to enable compilation of different datasets having different type of information on land-use, legends, and time period. The decision tree was built using structured query language (SQL) and implemented as a PostgreSQL function. The LU, VG, and AL, in overlapping, nearby, or different periods were selected and compiled together to make 6 different groups tagged with different time period, and were applied as input data for the decision tree as summarized in Table A1. As result, grid cells were classified into 9 land-use types; 01 paddy field (PD), 02 upland field (UP), 03 orchards (OC), 04 managed grassland (MG), 05 unmanaged grassland (UG), 06 forest lands (FL), 07 wetlands (WL), 08 settlements (ST), and 09 other lands (OL).

As any of these three geographical data sources alone could not fulfil requirement for our nation-wide simulation due to insufficient classification, accuracy, or time interval, we employed strategy to compile these different geographical data sources to set off merits against the deficit, and to interpret it; e.g. LU had more time series data than other data sources, however, in FY 1991-2006, its classification on agricultural land had only two legend items, 'paddy field' and 'other agricultural fields'. VG had more detail classifications but had only three time series data. Thus LU in FY 1991-2006 was superimposed with VG to enable subdivision of the legend item 'other agricultural fields' in LU into 'paddy field', 'upland field', 'orchards', and 'grasslands'.

Formulation of the decision tree was rather arbitrary and, thus, preliminary. A preliminary validation on the land-use maps using geographical reference dataset on agricultural land management collected in the Basic Soil Environment Monitoring Project, Stationary Monitoring conducted in year 1979-1998 showed that accuracy rate of the land-use map for paddy field, upland field, orchards, and managed grassland were 89, 76, 75, and 71 %, respectively, on average through four waves of the monitoring survey.

Table A1 Dataset used to composite land-use map.

Dataset	Period	land-use map				
		1976	1987	1991	1997	2006
Land use fragmented mesh data, Version 1.1 (LU) [1]	FY 1976	●				
	FY 1987		●			
	FY 1991			●		
	FY 1997				●	
	FY 2006					●
Vegetation map (VG) [2]	FY 1983-1986	●	●			
	FY 1989-1993			●		
	FY 1994-1998				●	●
Agricultural land map (AL) [3]	FY 2001					●

1) National Land Numerical Information (Land Use Fragmented Mesh), Ministry of Land, Infrastructure, Transport and Tourism (MLIT), Japan. http://nlftp.mlit.go.jp/ksj-e/jpgis/datalist/KsjTmplt-L03-b.html

2) Vegetation map, Vegetation Naturalness Survey, National Survey on the Natural Environment, Ministry of Environment, Japan.

3) Agricultural land map, Basic Survey on Improvement of Agricultural Production Base, Ministry of Agriculture, Forestry, and Fisheries, Japan.

Table A2 Spatial-temporal inventories employed in simulation.

Data type	Spatial resolution	Begin	End	Description
agricultural activity	Prefectural	1970	2008	estimate based on national statistics and survey on agriculture
climate	latitude: 1/120 ° longitude: 1/80 ° (ca. 1 x 1 km)	1970	1978	10 years mean values from observation between 1979 and 1988
		1979	2009	Observations
land-use	latitude: 1/1200 ° longitude: 1/800 ° (ca. 0.1 x 0.1 km)	1970	1976	identical to land-use map 1976 (no temporal change)
		1976	1987	interpolation of land-use map 1976 and 1987
		1987	1991	interpolation of land-use map 1987and 1991
		1991	1997	interpolation of land-use map 1991 and 1997
		1997	2006	interpolation of land-use map 1997 and 2006

Transformation of geodetic reference system, rasterization of the vector map, were performed using GDAL, OGR, GRASS GIS, Quantum GIS (QGIS), and tools provided by The Open Source Geo-spatial Foundation (OSGeo). Computational operations to compile LU, VG, and AL dataset and to superimpose them on the grid system were performed using PostGIS on PostgreSQL database.

Supplementary Material B. Key quantities on agricultural activity estimated for year 1970-2008

Table B1. Area of each land-use (employed in simulation), unit: 10^3 ha.

Land-use [1]	1970	1980	1990	2000	2008
01 PD	2,866	2,586	2,139	1,875	1,642
02 UP	1,453	1,621	1,845	1,806	1,809
03 OC	611	570	454	347	304
04 MG	505	560	647	630	580
sub-total	*5,435*	*5,337*	*5,085*	*4,657*	*4,335*
05 UG	956	1,024	1,235	1,500	1,537
06 FL	442	434	393	296	357
07 WL	48	46	38	38	38
08 ST	64	89	153	351	519
09 OL	85	100	126	188	245
Total	*7,030*	*7,030*	*7,030*	*7,030*	*7,030*

1) PD: paddy fields; UP: upland crop fields; OC: orchards; MG: managed grasslands; UG: unmanaged grasslands; FL: forest lands.

Table B2. Amount of plant residue input to fields (employed in simulation), unit: Gg C yr^{-1}.

Land-use [1]	1970	1980	1990	2000	2008
01 PD	4,204	3,460	3,923	4,338	3,947
02 UP	992	1,205	1,425	1,397	1,303
03 OC	341	331	294	275	252
04 MG	1,231	1,367	1,655	1,592	1,429
05 UG	3,634	3,891	4,695	5,700	5,841
06 FL	884	868	787	593	714
Total	*11,286*	*11,122*	*12,779*	*13,895*	*13,486*

1) PD: paddy fields; UP: upland crop fields; OC: orchards; MG: managed grasslands; UG: unmanaged grasslands; FL: forest lands.

Table B3. Number of livestocks, unit: 10^3 heads.

Livestock		1970	1980	1990	2000	2008
Dairy cow	milking	888	1,069	1,080	992	862
	heifer, dry	314	355	346	259	213
	U2Y [1]	608	646	605	513	458
Beef cattle	2YO [1]	831	723	854	870	994
	U2Y [1]	984	743	826	826	829
	dairy breed	186	716	1,039	1,123	1,067
Pigs	fattening	5,667	8,609	10,634	8,807	8,777
	breeding	844	1,169	1,182	1,000	967
Poultry	hen, 6MO [1]	43	34	40	38	39
	hen, U6M [1]	120	124	138	141	143
	broiler	55	128	151	108	103

1) 2YO: 2 years and older; U2Y: under 2 years old; U6M: under 6 months old; 6MO: 6 months and older.

Table B4. Amount of organic carbon in compost, slurry, and excreta from different sources (original estimate), unit: Gg C yr^{-1}.

	Sources	1970	1980	1990	2000	2008
Compost [2)]	LW	1,775	2,259	2,557	2,317	2,247
	BD	300	483	512	394	233
	SM	2,992	3,353	3,755	3,382	3,211
	FW	0	1	4	23	58
	ST	1,279	874	890	535	437
	sub-total	*6,346*	*6,970*	*7,718*	*6,651*	*6,186*
Slurry [1,2)]	SL_UP	17	18	18	14	12
	SL_MG	11	17	19	20	19
	sub-total	*28*	*35*	*37*	*34*	*31*
Excreta [1,2)]	EX_MG	15	21	24	25	25
Total		*6,389*	*7,026*	*7,779*	*6,710*	*6,242*

LW: livestock waste; BD: bedding for livestock; SM: secondary materials for composting livestock waste; FW: food waste; ST: rice and wheat straw. SL_UP: slurry applied to upland fields; SL_MG: slurry applied to managed grasslands. EX_MG: excreta applied to managed grasslands.

1) A conversion factor of 0.5 was applied for above listed values of slurry and excreta prior to determination of the annual input of farm-yard manure in RothC to take account relatively fast decomposition of these organic matters compared to composted manure.

2) Values shown in this table were estimated based on agricultural field area data in national statistics and thus were not identical to those listed in Table 2 that used area data from land-use map data applied in simulation.

Table B5. Amount of manure applied to fields (employed in simulation), unit: Gg C yr^{-1}.

Land-use [1)]	1970	1980	1990	2000	2008
01 PD	2,191	1,855	1,138	807	692
02 UP	3,457	3,763	3,497	2,782	2,457
03 OC	577	524	381	398	340
04 MG	0	727	2,701	2,510	2,336
Total	*6,225*	*6,869*	*7,717*	*6,497*	*5,825*

1) PD: paddy fields; UP: upland crop fields; OC: orchards; MG: managed grasslands.

Table B6. Amount of slurry applied to fields (employed in simulation), unit: Gg C yr^{-1}.

Land-use [1)]	1970	1980	1990	2000	2008
02 UP	27	34	36	27	23
04 MG	37	33	39	39	35
Total	*64*	*67*	*75*	*66*	*58*

1) UP: upland crop fields; MG: managed grasslands.

Table B7. Amount of excreta input to field (employed in simulation), unit: Gg C yr^{-1}.

Land-use [1)]	1970	1980	1990	2000	2008
04 MG	54	40	47	49	46

1) MG: managed grasslands.

Table B8. Rate of plant residue application to fields, unit: Mg C ha^{-1} yr^{-1}.

Land-use [1]	1970	1980	1990	2000	2008
01 PD	1.5	1.3	1.8	2.3	2.4
02 UP	0.7	0.7	0.8	0.8	0.7
03 OC	0.6	0.6	0.7	0.8	0.8
04 MG	2.4	2.4	2.6	2.5	2.5

1) PD: paddy fields; UP: upland crop fields; OC: orchards; MG: managed grasslands.

Table B9. Rate of manure application to fields, unit: Mg C ha^{-1} yr^{-1}.

Land-use [1]	1970	1980	1990	2000	2008
01 PD	0.8	0.7	0.5	0.4	0.4
02 UP	2.4	2.3	1.9	1.5	1.4
03 OC	1.0	0.9	0.8	1.2	1.1
04 MG	0.0	1.3	4.2	4.0	4.0

1) PD: paddy; UP: upland fields; OC: orchards; MG: managed grasslands.

Table B10. Rate of overall input of organic carbon (sum of plant residue, manure, slurry, and excreta) to fields, unit: Mg C ha^{-1} yr^{-1}.

Land-use [1]	1970	1980	1990	2000	2008
01 PD	2.2	2.1	2.4	2.7	2.8
02 UP	3.1	3.1	2.7	2.3	2.1
03 OC	1.5	1.5	1.5	1.9	2.0
04 MG	2.5	3.8	6.8	6.6	6.6

1) PD: paddy fields; UP: upland crop fields; OC: orchards; MG: managed grasslands.

Supplementary Material C. Equations used to estimate application rate of organic amendments in agricultural fields

[Plant residues]

Equations set C.1 (plant residue production for major crops and vegetables);

Annual plant residue inputs to soils in different prefecture and year were estimated for each cropping group using the following equations;

Equation C.1.1: for rice, wheat, sweet potato, beans, millet, and vegetables;

$$\mathrm{RSC}_{cg,pr,y} = \begin{cases} \sum_{c=1}^{nc_{cg}} \left(\mathrm{YFW}_{c,pr,y}\right) \cdot \mathrm{YD2F}_{cg} \cdot \mathrm{RS2Y}_{cg} \cdot \mathrm{RSINC}_{cg,rg,y} \cdot \mathrm{RSCC}_{cg} \\ \sum_{c=1}^{nc_{cg}} \left(\mathrm{YFW}_{c,pr,y} \cdot \mathrm{YD2F}_{c} \cdot \mathrm{RS2Y}_{c}\right) \cdot \mathrm{RSINC}_{cg,rg,y} \cdot \mathrm{RSCC}_{cg} \end{cases}$$

Equation C1.2: for orchards, manure crops, and forage;

$$\mathrm{RSC}_{cg,pr,y} = \sum_{c=1}^{nc_{cg}} \left(\mathrm{RSCA}_{c,y} \cdot \mathrm{CA}_{c,pr,y}\right) \cdot \mathrm{RSINC}_{cg,rg,y} \cdot \mathrm{RSCC}_{cg}$$

Equation C1.2.1: orchards;

$$\mathrm{RSCA}_{c,y} = const_{c}$$

Equation C1.2.2: manure crops;

for crops other than grass,

$$\mathrm{RSCA}_{c,y} = \mathrm{BMCA}_{c}$$

$$\mathrm{BMCA}_{c} = \mathrm{YDWCA}_{c} \cdot (1 + \mathrm{BG2Y}_{c})$$

$$\mathrm{YDWCA}_{c} = constc$$

for Italian ryegrass,

See Equation C1.2.3.

for grass excluding Italian ryegrass (including mixed seeding of *Poaceae* and *Fabaceae*),

See Equation C1.2.4.

Equation C1.2.3: forage of Italian ryegrass;

$$\mathrm{RSCA}_{\mathrm{GRIR},y} = \mathrm{RSBGCA}_{\mathrm{GRIR},y}$$

$$\mathrm{RSBGCA}_{\mathrm{GRIR},y} = \mathrm{RSBGCA}_{\mathrm{GRP,1982-84}} \cdot \frac{\mathrm{YFW}_{\mathrm{GR},y}}{\mathrm{YFW}_{\mathrm{GR,1983}}}$$

Equation C1.2.4: forage of grass excluding Italian ryegrass (including mixed seeding of *Poaceae* and *Fabaceae*);

$$\mathrm{RSCA}_{\mathrm{GRNI},y} = \left(\mathrm{RSBGCA}_{\mathrm{GR},y} + \mathrm{RSUGCA}_{\mathrm{GR},y}\right) + \frac{\mathrm{BMCA}_{\mathrm{GR},y}}{\mathrm{YRRE}}$$

$$\mathrm{RSBGCA}_{\mathrm{GR},y} = \mathrm{RSBGCA}_{\mathrm{GRP},1982-84} \cdot \frac{\mathrm{YFWCA}_{\mathrm{GR},1997-2005}}{\mathrm{YFWCA}_{\mathrm{GRP},1997-2005}} \cdot \frac{\mathrm{YFWCA}_{\mathrm{GR},y}}{\mathrm{YFWCA}_{\mathrm{GR},1996}}$$

$$\mathrm{RSUGCA}_{\mathrm{GR},y} = \mathrm{RSUGCA}_{\mathrm{GRP},1982-84} \cdot \frac{\mathrm{YFWCA}_{\mathrm{GR},1997-2005}}{\mathrm{YFWCA}_{\mathrm{GRP},1997-2005}} \cdot \frac{\mathrm{YFWCA}_{\mathrm{GR},y}}{\mathrm{YFWCA}_{\mathrm{GR},1996}}$$

$$\mathrm{YFWCA}_{\mathrm{GR},1997-2005} = \sum_{y=1997}^{2005} \left(\frac{\mathrm{YFWCA}_{\mathrm{GRP,y}} \cdot \mathrm{CA}_{\mathrm{GRP,y}} + \mathrm{YFWCA}_{\mathrm{GRPF,y}} \cdot \mathrm{CA}_{\mathrm{GRPF,y}}}{\mathrm{CA}_{\mathrm{GRP,y}} + \mathrm{CA}_{\mathrm{GRPF,y}}}\right) / 9$$

$$\mathrm{BMCA}_{\mathrm{GR},y} = \mathrm{YDWCA}_{\mathrm{GR},1996} \cdot (1 + \mathrm{BG2Y}_{\mathrm{GR}}) \cdot \frac{\mathrm{YFWCA}_{\mathrm{GR},y}}{\mathrm{YFWCA}_{\mathrm{GRPF},1996}}$$

$$\mathrm{YDWCA}_{\mathrm{GR},1996} = \frac{\mathrm{YDWCA}_{\mathrm{GRPF},1996} \cdot \mathrm{CA}_{\mathrm{GRPF},1997-2005} + \mathrm{YDWCA}_{\mathrm{GRP},1996} \cdot \mathrm{CA}_{\mathrm{GRP},1997-2005}}{\mathrm{CA}_{\mathrm{GRPF},1997-2005} + \mathrm{CA}_{\mathrm{GRP},1997-2005}}$$

where,

RSC = mass of organic carbon in plant residue to be incorporated into soils in a year, Mg C yr^{-1}.

c = cropping type (e.g. tomato, two-row barley, Italian ryegrass, etc.).

cg = cropping group (e.g. paddy rice, wheat, vegetables, forage and manure crop, etc.).

nc = the number of cropping types in a cropping group (paddy rice (3); wheat (4); sweet potato (1); beans (4); millet (1); vegetables (38); forage and manure crop (8); industrial crop (3); fruit and tea (2)).

ncg = the number of cropping groups in a land-use type (paddy fields (3); upland fields (7); orchards (1); managed grasslands (1)).

pr = prefecture.

rg = region (group of prefectures).

y = year.

const = fixed constant taken from literatures.

YFW = yield in fresh weight, Mg yr^{-1}.

YD2F = proportion of dry weight against fresh weight of yield.

RS2Y = proportion of residues by weight against yield, dry weight basis.

RSINC = proportion of plant residues to be returned to soils against other usages or treatments such as bedding for live-stock, handicraft, incineration, and disposal.

RSCC = concentration of organic carbon in plant residue, dry matter basis, g g^{-1}.

CA = cropping area, ha.

RSCA = plant residue production per a unit cropping area in a year, Mg ha^{-1} yr^{-1}.

BMCA = total biomass of grass including above and below ground biomass per unit cropping area, Mg ha^{-1}.

YDWCA = yield per a unit cropping area in a year in dry weigh, Mg ha^{-1} yr^{-1}.

YFWCA = yield per a unit cropping area in a year in dry weigh, Mg ha^{-1} yr^{-1}.

BG2Y = proportion of below ground biomass against yield in dry weight.

RSBGCA = below ground biomass residue input to soils per a unit cropping area in a year, Mg ha^{-1} yr^{-1}.

RSUGCA = upper ground biomass residue input to soils per a unit cropping area in a year, Mg ha^{-1} yr^{-1}.

YRRE = mean of number of years for renewal of grasslands.

GR = grass.

GRIR = Italian ryegrass.

GRNI = grass excluding Italian ryegrass.

GRP = grass of *Poaceae* family, e.g. Italian ryegrass.

GRPF = grass with mixed seeding of *Poaceae* and *Fabaceae* families.

Equation C.1.3 (plant residue input to soil in different land-use types);

$$\mathrm{RSCI}_{lu,pr,y} = \sum_{cg=1}^{ncg_{lu}} \left(\mathrm{RSC}_{cg,pr,y}\right) / \mathrm{A}_{lu,pr,y}$$

where,

RSCI = annual rate of plant residue organic carbon input to soils, Mg C ha^{-1} yr^{-1}.

lu = land-use type, including paddy fields, upland fields, orchards, and managed grasslands.

pr = prefecture.

y = year.

cg = cropping group (e.g. paddy rice, wheat, vegetables, forage and manure crop, etc.).

ncg = the number of cropping groups in a land-use type (paddy fields (3); upland fields (7); orchards (1); managed grasslands (1)).

A = area of field in each land-use type, ha.

Table C1 List of parameters used for estimation for production and application of plant residues.

crop group		YD2F 1)	RSCA 2)	RS2Y 3)	RSINC 4)	BMCA 5)	YRRE 6)	RSCC 7)
rice (1)	straws			1.20	0.32-0.64-0.95			
	husks	0.85		0.22	0-0.20-0.35			
	roots & stables			0.27	1.0			
wheat (4)	shoots	0.85		0.97	0-0.63-1.0			
	roots & stables			0.42	1.0			
sweet potato (1)		0.30		0.50	0.46			0.4
beans (4)		0.85-0.90		0.9-1.0	0.75			
millet (1)		0.85		1.50	0.46			
vegetables (29)		0.05-0.25		0.2-5.0	0.46			
orchards (18)			1.0-15.4		1.0			
forage & manure crops (9)			3.6-15.9		1.0	5.6-17.2	10	

Two values separated with hyphen indicate minimum and maximum values, whereas three values separated with two hyphens indicate minimum, mean, and maximum values of parameter.

1) YD2F: proportion of dry weight against fresh weight of yield.

2) RSCA: proportion of residues by weight against yield, dry weight basis.
3) RS2Y: proportion of residues by weight against yield, dry weight basis.
4) RSINC: proportion of plant residues to be returned to soils against other usages or treatments such as bedding for live-stock, handicraft, incineration, and disposal.
5) BMCA: total biomass including both above and below ground biomass per unit cropping area, Mg ha^{-1}.
6) YRRE: mean of number of years for renewal of grasslands.
7) RSCC: concentration of organic carbon in plant residue, dry matter basis, g g^{-1}. Parameter value was taken from Shirato et. al. (unpublished).

[Live-stock waste compost]

Equation C.2.1 (Live-stock waste);

$$\mathrm{LWFW}_{ls,pr,y} = \sum_{lss=1}^{nlss_{ls}} \left(\mathrm{LSN}_{lss,pr,y} \cdot \mathrm{LWE}_{lss} \cdot \mathrm{DN}_{y}\right)$$

where,

ls = live-stock type, including dairy cattle, beef cattle, swine, hen, and broiler.

pr = prefecture.

y = year.

LWFW = mass of live-stock waste produced in a year, in fresh weight, Mg y^{-1}

LSN = the number of head of live-stock

LWE = rate of emission of live-stock waste (excrement) in fresh weight per a head of live-stock, kg d^{-1} $head^{-1}$

DN = the number of days in a year

lss = live-stock sub-category, based on class of age or utilization

nlss = the number of live-stock sub-category in different live-stock types (dairy cattle (3); beef cattle (3); swine (2); hen (2); broiler (1))

Equation C.2.2 (Live-stock waste to be utilized for composting, in different type of live-stock);

$$\mathrm{LW4LC}_{ls,pr,y} = \mathrm{LWFW}_{ls,pr,y} \cdot \mathrm{LWCOMP}_{ls}$$

$$\mathrm{LW4SL}_{ls,pr,y} = \mathrm{LWFW}_{ls,pr,y} \cdot \mathrm{LWSL}_{ls}$$

where,

LW4LC = mass of live-stock waste to be utilized for composting (to produce LWC)

LW4SL = mass of live-stock waste to be utilized for slurry production (to produce LWC)

ls = live-stock type, including dairy cattle, beef cattle, swine, hen, and broiler.

pr = prefecture.

y = year.

LWFW = mass of live-stock waste produced in a year, in fresh weight, Mg y^{-1}

LWCOMP = proportion of live-stock waste to be utilized for composting against other usages.

LWSL = proportion of live-stock waste to be utilized for slurry production against other usages.

Equation C.2.3 (Live-stock waste to be utilized for composting, sum of all types of live-stock);

$$\mathrm{LWC}_{pr,y} = \sum_{ls=1}^{nls} \left(\mathrm{LW4LC}_{ls,pr,y} \cdot \mathrm{LWD2F}_{ls} \cdot \mathrm{LWDC}_{ls} \cdot \mathrm{LWCC}_{ls}\right)$$

$$\mathrm{SLC}_{pr,y} = \sum_{ls=1}^{nls} \left(\mathrm{LW4SL}_{ls,pr,y} \cdot \mathrm{LWD2F}_{ls} \cdot \mathrm{LWCC}_{ls}\right)$$

where,

LWC = mass of organic carbon in live-stock waste compost derived from live-stock waste produced in a year in dry weight, Mg C y^{-1}.

SLC = mass of organic carbon in slurry derived from live-stock waste produced in a year in dry weight, Mg C y^{-1}.

pr = prefecture.

y = year.

ls = live-stock type, including dairy cattle, beef cattle, swine, hen, and broiler.

nls = number of live-stock types.

LW4LC = mass of live-stock waste to be utilized for composting (to produce LWC)

LW4SL = mass of live-stock waste to be utilized for slurry production (to produce LWC)

LWD2F = proportion of dry weight against fresh weight of live-stock waste (excrement)

LWDC = residual ratio of live-stock waste after decomposition during composting.

LWCC = concentration of organic carbon in live-stock waste in dry weigh basis, g g^{-1}.

Equation C.2.4 (secondary materials to be utilized for live-stock waste compost production);

$$\mathrm{SMC}_{pr,y} = \sum_{sm=1}^{nsm} \left(\mathrm{LWCOMP}_{pr,y} \cdot \mathrm{SM2LW}_{sm} \cdot \mathrm{SMD2F}_{sm} \cdot \mathrm{SMDC}_{sm} \cdot \mathrm{SMCC}_{sm}\right)$$

where,

SMC = mass of organic carbon in live-stock waste compost derived from secondary materials produced in a year, Mg C y^{-1}

pr = prefecture.

y = year.

sm = secondary material type, including straw, husks, saw-dust, and bark.

nsm = number of secondary materials to be used for composting live-stock waste.

LWCOMP = proportion of live-stock waste to be utilized for composting against other usages.

SM2LW = proportion of applied secondary materials against live-stock waste during composting, based on survey data.

SMD2F = proportion of dry weight against fresh weight of secondary materials for live-stock waste composting.

SMDC = residual ratio of secondary materials used for live-stock waste composting after decomposition during composting.

SMCC = concentration of organic carbon in secondary materials, g g^{-1}.

Equation C.2.5 (bedding materials for live-stock farming used for live-stock waste composting);

$$\mathrm{BDC}_{pr,y} = \sum_{bd=1}^{nbd} \left\{ \left(\sum_{ls=1}^{nls} \mathrm{LSN}_{ls} \cdot \mathrm{BD2LS}_{bd,ls} \right) \cdot \mathrm{BDD2F}_{bd} \cdot \mathrm{BDDC}_{bd} \cdot \mathrm{BDCC}_{bd} \right\}$$

where,

BDC = mass of organic carbon in live-stock waste compost derived from bedding materials for live-stock, Mg yr^{-1}.

bd = bedding materials for live-stocks, including rice-straw, saw-dust, wheat straw, dry grass, hey, and others.

nbd = number of bedding materials for live-stocks.

ls = type of live-stock, including dairy cattle, beef cattle, swine, hen, and broiler.

nls = number of types of live-stock

LSN = the number of head of live-stock.

BD2LS = mass of bedding materials to be applied per a head of live-stock, based on survey data, Mg head^{-1} yr^{-1}.

BDD2F = proportion of dry weight against fresh weight of bedding materials.

BDDC = residual ratio of bedding materials after decomposition during composting.

BDCC = concentration of organic carbon in bedding materials, g g^{-1}.

Equation C.2.6 (food waste to be utilized for composting);

$$\mathrm{FWC}_{pr,y} = \sum_{fi=1}^{nfi} \left(\mathrm{FWCOMP}_{fi,jp.y} \cdot \frac{\mathrm{PN}_{pr,y}}{\mathrm{PN}_{jp,y}} \right) \cdot \mathrm{FWD2F} \cdot \mathrm{FWDC} \cdot \mathrm{FWCC}$$

where,

FWC = mass of organic carbon in compost derived from food waste in a year, Mg yr^{-1}.

pr = prefecture.

y = year.

fi = food industry, including manufacturing, wholesale business, retailing, and foodservice.

nfi = number of food industry

jp = Japan.

FWCOMP = mass of food waste to be utilised for composting in fresh weight, Mg yr^{-1}.

PN = human population in a geographic administrative entity (prefecture or country).

FWD2F = proportion of dry weight of food waste against fresh weight.

FWDC = residual ratio of food waste after decomposition during composting.

FWCC = concentration of organic carbon in food waste, g g^{-1}.

Equation C.2.7 (mass of organic carbon in live-stock waste compost produced in a year);

$$\mathrm{LCC}_{pr,y} = \mathrm{LWC}_{pr,y} + \mathrm{SMC}_{pr,y} + \mathrm{BDC}_{pr,y} + \mathrm{FWC}_{pr,y}$$

where,

LCC = mass of organic carbon in live-stock waste compost produced in a year, Mg yr^{-1}.

pr = prefecture.

y = year.

LWC = mass of organic carbon in live-stock waste compost derived from live-stock waste produced in a year in dry weight, Mg C yr^{-1}.

SMC = mass of organic carbon in live-stock waste compost derived from secondary materials produced in a year, Mg C yr^{-1}.

BDC = mass of organic carbon in live-stock waste compost derived from bedding materials for live-stock produced in a year, Mg C yr^{-1}.,

FWC = mass of organic carbon in live-stock waste compost derived from food waste produced in a year, Mg C yr^{-1}.

Equation C.2.8 (mass of live-stock waste compost applied to soils in different land-use in a year, except managed grasslands);

$$\mathrm{LCC}_{lu,pr,y} = \sum_{cg=1}^{ncg_{lu}} \left(\mathrm{LCI}_{cg,pr,y} \cdot \mathrm{CA}_{cg,pr,y} \cdot \mathrm{FRT}_{cg,lu} \cdot \mathrm{LCD2F} \cdot \mathrm{LCCC}\right)$$

where,

LCC = mass of organic carbon in live-stock waste compost applied to soils in all land-use types in a year, Mg C yr^{-1}.

lu = land-use types, including paddy fields, upland fields, and orchards.

pr = prefecture.

y = year.

cg = cropping group.

ncg = number of cropping group.

LCI = rate of annual live-stock waste compost application to soil, based on questionnaire to farmer, in fresh weight, Mg C ha^{-1} yr^{-1}.

CA = cropping area, ha

FRT = fraction of cumulative cropping area in a year to field area (times of rotation in a year)

LCD2F = proportion of dry weight of live-stock waste compost against fresh weight.

LCCC = concentration of organic carbon in live-stock waste compost, g g^{-1}.

Equation C.2.9 (mass of organic carbon in live-stock waste compost applied to soils in managed grasslands);

$$\mathrm{LCC}_{MG,pr,y} = \mathrm{LCC}_{pr,y} - \sum_{lu=1}^{nlu} \mathrm{LCC}_{lu,pr,y}$$

where,

LCC_{MG} = mass of organic carbon in live-stock waste compost applied to soils in managed grasslands, Mg C yr^{-1}.

pr = prefecture.

y = year.

lu = land-use types, including paddy fields, upland fields, and orchards.

nlu = number of land-use types, including paddy fields, upland fields, and orchards.

Equation C.2.10 (input of live-stock waste compost to soils);

$$\mathrm{LCCI}_{lu,pr,y} = \mathrm{LCC}_{lu,pr,y}/\mathrm{A}_{lu,pr,y}$$

where,

LCCI = rate of application of organic carbon in live-stock waste compost to soils per unit area of fields, Mg C ha^{-1} yr^{-1}.

lu = land-use types, including paddy fields, upland fields, orchards, and managed grasslands.

pr = prefecture.

y = year.

LCC = mass of organic carbon in live-stock waste compost applied to soils, Mg C yr^{-1}.

A = area of fields, ha.

Supplementary Material D. Soil inventories

Some details on the soil inventories in Japan used in this study are described below;

D1. Soil inventories

1. '*Chiryoku hozen kihon chousa*' (in Japanese; i.e. basic survey for soil fertility conservation), conducted in year 1959-1978, that had been conducted to compile soil map for agricultural lands and collected data on attributes of soil horizons from ca. 20,000-25,000 soil profiles throughout Japan. A sub-set called '*Kanni danmen chousa*' (in Japanese; i.e. simple soil profile survey) contains data on attributes of surface and sub-surface soil layers from ca. 25,000 sampling sites, except Kyoto and Wakayama prefecture, whereas another sub-set called '*Daihyou danmen chousa*' (in Japanese; i.e. representative soil profile survey) contains data on attributes of soil horizons from ca. 20,000 soil profiles (Nihon Dojo Kyoukai, 2002).

2. '*Dojo kankyo kiso chousa, Teiten chousa*' (in Japanese; basic soil environment monitoring project, stationary monitoring), conducted during year 1979-1998 with a series of 4 waves with interval of 4-5 years had collected soil samples from ca. 20,000 survey points in agricultural lands (Agricultural Production Bureau, Ministry of Agriculture Forestry and Fisheries, 2008).

3. '*Dojou tanso chousa jigyou'* (in Japanese; soil carbon survey project), having been conducted since year 2008, monitoring changes in SOC stock with annual interval, in about 3,000 survey points (Ondanka taisaku dojou kinou chousa kyougikai, 2013). Inclusion of managed grasslands in monitoring sites setup is a feature of this survey as the managed grasslands were either not explicitly surveyed or included only a few in the above listed past soil survey 1 and 2, respectively.

D2. Methodology of the measurement of SOC concentration in existing soil inventories

With regard to methodology of the measurement of SOC concentration in above mentioned datasets, we can indicate the followings based on some document-based evidences, observations and knowledge of experts;

A) In the soil survey in year 1959-1977, it is considered that wet oxidation methods (e.g. known as Tyurin method or Walkley Black method) were used as major analytical procedures, while including some possibility for a use of dry combustion method in later stage. A document-based, immediate reference on methodology is not available (i.e. at least not attached with the dataset). Conducting a survey through old domestic reports might find some relevant information on the methodology, however, will not be enough to fully elucidate it as many different laboratories conducted the analysis.

B) In the stationary monitoring in year 1979-1998, operation manual for soil chemical analysis did specify to use either dry or wet combustion methods and not to use wet-oxidation methods. However, no record on selection of the method exists in the dataset.

As to methodologies used to determine SOC concentration in these datasets, it is considered wet-oxidation methods (e.g. known as Tyurin method or Walkley and Black method) were used as a major methodology in the soil survey for compiling soil map. No records or document-based evidence on which methodology has been used are attached to this dataset. Whereas in the stationary monitoring, either dry or wet combustion methods were used. Although, no record on selection of the method exists in this dataset.

References

Agricultural Production Bureau, Ministry of Agriculture Forestry and Fisheries: Dojou hozen chousa jigyou seisekisyo., 2008.

Nihon Dojo Kyoukai: Chiryoku hozen dojouzu de-ta CD-ROM (Zenkoku-ban), 2002.

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