



HOKKAIDO UNIVERSITY

Title	Eco-balance analysis of land use combinations to minimize environmental impacts and maximize farm income in northern Japan
Author(s)	Kimura, Sonoko D.; Toma, Yo; Mu, Zhijian et al.
Citation	Sustainability Science, 5(1), 19-27 https://doi.org/10.1007/s11625-009-0100-6
Issue Date	2010-01
Doc URL	https://hdl.handle.net/2115/43230
Rights	The original publication is available at www.springerlink.com
Type	journal article
File Information	SS5-1_19-27.pdf



1 Eco-balance analysis of land use combinations to minimize
2 environmental impacts and maximize farm income in
3 northern Japan
4
5

6 Sonoko D. KIMURA^{*1}, Yo TOMA², Zhijian MU³ Hiroyuki YAMADA⁴ and Ryusuke
7 HATANO⁴
8

9 ¹ Tokyo University of Agriculture and Technology, Graduate School of
10 Agriculture, Tokyo Japan,

11 ² Hokkaido University, Field Science Center for Northern Biosphere, Sapporo,
12 Japan,

13 ³ South West University, Key Laboratory of Agricultural Resources and
14 Environmental Research, College of Resources and Environment, Chongqing,
15 China,

16 ⁴ Hokkaido University, Graduate School of Agriculture, Sapporo, Japan,
17

18 *Corresponding author: Graduate School of Agriculture, Tokyo University of
19 Agriculture and Technology 3-5-8 Saiwaicho Fuchu, Tokyo, 183-8509 Japan.
20 Tel/Fax +81-42-367-5952. E-mail: skimura@cc.tuat.ac.jp
21

22 Abstract

23 Relationships between global warming potential (GWP), farmland surplus nitrogen
24 (FSN) and income for major land uses in Ikushunbetsu watershed were compared using the
25 eco-balance method. An empirical model was created for carbon dioxide, methane and
26 nitrous oxide for both uplands and paddy rice using monitoring data from 22 fields. The
27 greenhouse gas emissions were converted into GWP, whereas yield and FSN were
28 obtained from farmers' interviews and literature survey. Land use distribution was obtained
29 by ground survey in 2002, 2005 and 2007. The analysis showed that paddy rice and
30 soybean were characterized by high GWP, low FSN and high income, whereas onion and
31 vegetables had high FSN but low GWP and moderate income. Wheat showed negative

32 GWP in some years and abandoned area always exhibit negative values. The total GWP for
33 the region was 14184, 11085 and 8337 Mg CO₂ yr⁻¹ for 2002, 2005 and 2007, respectively.
34 The contribution of paddy rice to GWP was highest, ranging from 40% to 75%. To find
35 optimal land use combinations that have higher income and lower GWP and FSN than
36 present, all possible land use combination was analyzed by changing the land use
37 proportion from 0 -100% at an interval of 10%. The number of land use combinations
38 meeting the requirements in the three investigated years was 205. Abandoned area which
39 had the smallest environmental load was included in every land use combination, indicating
40 that land uses with low environmental impacts should be maintained at a certain proportion
41 to mitigate the environmental load accompanying land uses with high production.

42

43 **Keywords**

44 Eco-balance, farmland soil, farmland surplus nitrogen, global warming potential, land use

45

46 **Introduction**

47 Based on the consensus definition of “sustainable growth” (World Commission on
48 Environment and Development 1987), analysis of production systems has been conducted
49 to achieve the highest productivity with the least environmental loads. Analysis method such
50 as life cycle assessment (ISO 14000 Information Centre 2002) is a strong tool for this
51 purpose. In agricultural production on farmland, the relation of productivity and
52 environmental load must also be analyzed comprehensive and quantitatively to provide a
53 criteria for choosing the most environmentally-friendly management method to farmers and
54 policy makers. However, quantification of nutrient flow in agroecosystem is difficult due to
55 the diverse environmental condition ruling the agricultural production. Characteristics of soil
56 influence the nutrient leaching rate or green house gas fluxes (Gu et al. 2007, Tan et al.
57 2009). Climate condition changes among years, and a dry and hot year has different
58 environmental concerns than a wet and cold year due to different soil organic matter
59 mineralization rate (Franzluebbers et al. 2001) or susceptibility of applied nitrogen (N)
60 fertilizer to ammonia evaporation (Sutton et al. 2000). In addition, recent environmental
61 loads concerning nutrient cycle, such as global climate change, acid deposition or
62 eutrophication are found not only at the local source area where the pollutant is emitted, but

63 regionally and even globally. The flow of pollutants must be quantified and evaluated at a
64 regional to global scale.

65 Since most researches on nutrient flow in agroecosystems are conducted at field scale,
66 monitoring data at the fields must be scaled up to regional scale. The up-scaling of
67 monitoring data can be described in several steps (Kimura et al. 2009). The first step is the
68 parameterization of the data monitoring; in which the data are explained by environmental
69 factors. The second step is to get information about the spatial variability. At this step,
70 parameters able to reflect the spatial variation of the target scale must be drawn to a GIS
71 map. The third step is the quantification of the flow and its validation and uncertainty
72 analysis. The final step is the evaluation of the estimated flows and its optimization and
73 mitigation of environmental load.

74 The challenge of the parameterization is to cover additional information or relationship
75 by more easily obtained data at a larger scale than the monitoring is conducted (Seyfried
76 2003). At the second step, the accuracy is important. If the gained parameters are of
77 reduced accuracy, the estimated result has also reduced the accuracy. In most fundamental
78 sense, the loss of accuracy with up-scaling is due to the error caused in reflecting the spatial
79 variability. The validation of the estimation is difficult, and sometimes impossible to verify the
80 results. Several methods have been suggested such as verification of the most important
81 process in the extrapolation mechanism (Wagenet 1998) or verification of the N budget with
82 particular attention to water quality (Randall and Gross 2001) The final most important step
83 is the evaluation of the results to show optimization measures. Kimura and Hatano (2007)
84 have proposed an evaluation method, which compare the environmental load to the
85 productivity to analyze the relation of them. The method is defined as eco-balance analysis.

86 In this study, an eco-balance analysis was conducted using monitoring results of green
87 house gas emissions (GHG) from different land uses and farmland surplus nitrogen (FSN)
88 survey conducted in a watershed scale. Green house gas emissions were parameterized
89 and an empirical regional scale model for nitrogen and carbon flow was created (Kimura et
90 al. 2007). Management methods and productivity were obtained by farmer's inquiry. The
91 objective of this study was to conduct a quantitative analysis of the relation of GHG emission
92 and FSN to the economic benefit of the land use for the year 2002, 2005 and 2007. Optimal
93 land use combination throughout the years can be suggested based on the analysis.

94

95 Study site

96 This study area was Ikushunbetsu River watershed in the central part of Hokkaido 42
97 km north west from Sapporo (N 43°14', E 141°.57' at the middle of the basin; Figure 1). The
98 Ikushunbetsu River watershed covers an area of 35,887ha and represents a branch of the
99 Ishikari River. The 30-year average annual temperature was 7.4°C, and the annual
100 precipitation 1154mm (Sapporo Distinct Meteorological Observatory 2008). Crop growing
101 was possible after the snow-melt in April until snow-fall in the middle of November. The total
102 area of artificial land uses in the basin since 1905 was 3442 ha. The main agricultural land
103 uses are paddy rice, onion, wheat and grassland. Vegetables such as tomato and cucumber,
104 and soybean represented minor crops. The soils of the area are mostly Fluvisols near the
105 river and Cambisols at higher elevations (Hokkaido Central Agricultural Experiment Station
106 1971).

107

108 Methods

109 Greenhouse gas fluxes were measured in 22 fields comprising 11 land use types using
110 closed chamber method over a period of 13 years from 1995 to 2008. Carbon dioxide (CO₂)
111 flux from soil organic carbon (C) decomposition was measured on bare soil, nitrous oxide
112 (N₂O) and methane (CH₄) fluxes were measured on planted soils (for detail see Kusa et al.
113 2002, Naser et al. 2007, Toma et al. 2007, Mu et al. 2008a, 2008b). Annual cumulative flux
114 of each gas was parameterized using soil, climate and management parameters. The GHGs
115 were converted into GWP (Intergovernmental Panel on Climate Change 2007), where 1 g
116 CH₄ and 1 g N₂O are equivalent to the global warming potential of 25 g and 298 g CO₂ at
117 100 year time horizon, respectively.

118 Carbon (C) sequestration (kg C ha⁻¹ yr⁻¹) was calculated as follows:

119

120 C sequestration = net primary production + C in manure – soil organic C
121 decomposition – C in harvested products --- Equation (1)

122

123 Soil organic C decomposition (kg C ha⁻¹ yr⁻¹) = 49.7× (Water filled pore space (%)) +
124 217.0× (soil temperature at 5cm (° C)) - 144.8× (CN ratio) - 58.7× (clay

125 content (%) + 2807.3 (P=0.012) --- Equation (2)

126

127 For Soil organic C decomposition for perennial vegetation such as grassland and
128 abandoned area a fixed value of 1691.3 kg C ha⁻¹ yr⁻¹ (Mu et al. 2008a) was used.

129

130 Nitrous oxide flux (kg N ha⁻¹ yr⁻¹) of an upland field was estimated using emission
131 factors (EF: proportion of N₂O emission to applied nitrogen) on the basis of the following
132 assumption (Toma et al. 2007):

133

134 N₂O flux = EF chemical fertilizer × applied chemical fertilizer
135 + EF organic matter × applied organic matter + background N₂O emission

136 --- Equation (3)

137

138 The EF was created for onion fields. To consider the difference in CN ratio of different crop
139 residue, the EF was parameterized following Toma and Hatano (2007). Since the
140 background N₂O emission was only measured at cultivated fields and the rate was higher
141 than the reported values for background emission, a fixed value of 1 kg N ha⁻¹ yr⁻¹
142 (Intergovernmental Panel on Climate Change 1996) was used for fallow and bushes.

143 The CH₄, CO₂ and N₂O flux for a paddy rice field showed a high correlation with the
144 applied amount of straw and were expressed as a function of amount of straw residues
145 (Naser et al. 2007).

146

147 Farmland surplus N (kg N ha⁻¹ yr⁻¹) was calculated based on equation 4 and 5. Note
148 that the plant residue is considered as input and the total N uptake by plants as output.
149 Thus the actual output is only the harvested N in plant.

150

151 Farmland input N = chemical fertilizer + manure + green manure + residue
152 + biological N₂ fixation + deposition and irrigation --- Equation (4)

153

154 Farmland surplus N = N input to farmland – total N uptake by plants (yield plus
155 residue) – denitrification

156 – NH₃ volatilization from chemical fertilizer and manure – N₂O emission

157 --- Equation (5)

158

159 A ground survey was conducted in 2002, 2005 and 2007 to locate the land uses and the
160 land use distribution was mapped digitally using ArcView 9. Land use history was analyzed
161 using 1:25,000 maps from geographical survey institute (1959, 1966, 1976, 1988, 1994).
162 Fallow was defined as area with previous artificial land use but no cultivation or construction
163 in the ground survey years. The area which was identified as fallow since 1994 was termed
164 'abandoned area'. Farmer's interviews were conducted in 2002, 2005 and 2007 to obtain
165 information on management practices and land use distribution in the study area.
166 Questionnaires were distributed to farmers where information on amount and type of
167 fertilizer, timing of application, incorporation methods and final yield were obtained. There
168 were 161 farms in 2002 in this area. Among them 34 were sown to paddy rice, 14 to wheat,
169 3 to soybean, 49 to onion, 19 to vegetable, 3 were grassland, and 5 were fallow. Yield
170 values were multiplied by the ratio of main product to by product (Matsumoto 2000) to
171 calculate the net primary production and amount of N in the crop by measuring the CN ratio
172 (SUMIGRAPH NC – 1000, SHIMADZU, Kyoto, Japan). Values not obtained from our
173 monitoring were obtained from literature (see Kimura et al. 2007 for more detail).
174 Productivity was evaluated by multiplying the price of sold product by area for each year
175 (Ministry of Agriculture, Forestry and Fishery 2009a).

176

177 Result and discussion

178 Land-use change from 2002 to 2007

179 Urban area was the largest artificial land use with occupying about 28% of the
180 landscape throughout the 3 investigated years (Figure 2). The next largest land use was
181 fallow, due to the closure of mine activity in 1989 (Mikasa City 1994) and recent agricultural
182 activity in this area (Kimura et al. 2004). Among farmlands, paddy rice occupied the largest
183 land area (14%) followed by onion (11%) in 2002. Both paddy rice and onion declined to 2%
184 from 2002 to 2007. The decline in paddy rice area is encouraged by the set aside policy of
185 the Japanese government (Ministry of Agriculture, Forestry and Fishery 2007). The decline
186 in onion area might be due to the low onion price in 2002 as described later. Grass and

187 vegetable increased in extent during this period. Cultivation of fodder crop, soybean and
188 fodder crops were substituted by the Japanese government (Ministry of Agriculture, Forestry
189 and Fishery 2009b). The increase in grass from 6% to 10% might have been driven by the
190 by this set aside policy.

191

192 Farmland management

193 Nitrogen input for the main land uses was calculated as the sum of chemical fertilizer,
194 manure, green manure and crop residues, biological N₂ fixation and N from deposition and
195 irrigation (Table 1). The highest input for paddy rice, wheat, onion and vegetable derived
196 from chemical fertilizer, whereas that for soybean and grass was from biological N₂ fixation
197 and manure, respectively. The highest N input for fallow and abandoned area was from
198 green manure. Total input was highest for onion at 487.7 kg N ha⁻¹ yr⁻¹, followed by
199 vegetable at 423.1 kg N ha⁻¹ yr⁻¹. The standard deviations were very high for both land
200 uses, indicating very low N inputs for some fields. Exceptionally high deviations were also
201 observed for manure applications. Grass showed the third highest N input with 204.9 kg N
202 ha⁻¹ yr⁻¹. The lowest N inputs were found for fallow and abandoned area with 94.2 and 85.0
203 kg N ha⁻¹ yr⁻¹, respectively. Some fallow areas were fertilized and cultivated with green
204 manure, thus, there was a high deviation in chemical fertilizer input.

205 The Nitrogen in yield did not differ greatly among the years, except for paddy rice and
206 vegetable (Table 2). Paddy rice had the lowest amount of 49.0±4.3 kg N ha⁻¹ yr⁻¹ in 2002.
207 Farmers with yields much lower than the average might have been included in the
208 investigation 2002. The higher yield of vegetable in 2005 and 2007 compared to 2002 is due
209 to including more vegetable types in 2005 and 2007 than in 2002. The inclusion of various
210 vegetable types also increased the standard deviation. The FSN was calculated using the
211 equation 4. Farmland surplus N showed consistent tendency throughout the years. Onion
212 had the highest surplus ranging from 154.5-187.5 kg N ha⁻¹ yr⁻¹, followed by the vegetables
213 (128.6-172.3 kg N ha⁻¹ yr⁻¹). Fallow and abandoned area showed a FSN of 15.5-20.3 and
214 6.8-12.3 kg N ha⁻¹ yr⁻¹, respectively. Paddy rice showed as low FSN as fallows, whereas the
215 lowest FSN was found for soybean with negative to slightly positive amount.

216 Income for main land uses in 2002, 2005 and 2007 are shown in Table 3. The difference
217 in the values is mainly due to fluctuations in market prices. There were high variations for

218 paddy rice, soybean and vegetable. The highest income per ha was for vegetable in 2002,
219 soybean in 2005 and rice in 2007. In 2005 and 2007, the lowest income was found for grass
220 followed by onion. The income for grass might be lower in reality, since this cost was
221 calculated for commercial hay and the grass is not sold but consumed inside the farm in this
222 region.

223

224 Global warming potential of the soils

225 The average GWP for the major land uses are shown in Figure 3. Calculations of GWP
226 were based on soils occupied by the different land uses (Hokkaido Central Agricultural
227 Experiment Station 1971). Paddy rice and soybean showed the highest GWP of more
228 than 10 Mg CO₂ eq ha⁻¹ yr⁻¹ throughout the investigated period. Methane accounted for 75%
229 of the GWP for paddy, whereas both N₂O and CO₂ were responsible for the relatively high
230 GWP for soybean. The lowest GWP was observed for abandoned land as the relatively high
231 amount of plant biomass lead to lower N₂O emission and higher carbon sequestration
232 compared to other land uses. Changes in GWP for other land uses were observed between
233 2002 and 2007 due to differences in N₂O emission and soil carbon decomposition. Low
234 emissions of N₂O or organic fertilizer application in 2007, possibly led to negative GWP for
235 abandoned area, fallow and wheat.

236 Global warming potential is higher for paddy rice fields and soybean than a previous
237 study (Kimura et al. 2007) apparently due to the increase from 22-57 farms to 127 farms in
238 the current study. In the new inventory, more farmers were included who incorporate green
239 manure and livestock manure into the production system. The standard deviation is higher,
240 but the value might reflect more precisely the real situation in the study area. The calculation
241 of N₂O emission as well as soil carbon decomposition has also been improved compared to
242 the previous study to reflect climate and soil properties. N₂O emission as high as 15.6 kg N
243 ha⁻¹ yr⁻¹ had been recorded in this region in recent years (Kusa et al. 2002). High
244 background emission ranging from 1.81-12.1 kg N ha⁻¹ yr⁻¹ may also be playing a role (Toma
245 et al. 2007). The GWP reported for upland crop for European Union countries was 0.7–25
246 Mg CO₂ eq ha⁻¹ yr⁻¹ with an average value of 2.0 Mg CO₂ eq ha⁻¹ yr⁻¹ (Freibauer 2003). The
247 value in the present study might not be extremely high compared to this result. The
248 comparison of the 3 years shows that global warming potential may change dramatically if

249 the amount of residue and/or soil respiration changes, as shown in the case of wheat.

250 The cumulative GWP for the whole farmland area declined from 14,184 Mg CO₂ yr⁻¹ in
251 2002 to 8337 Mg CO₂ yr⁻¹ in 2007 (Figure 5). The contribution of paddy rice was highest
252 ranging from 54% in 2005. to 90% in 2007 The high amount (11085 Mg CO₂ yr⁻¹) in 2005
253 was also due to high GWP of wheat and onion, with each contributing 12% of the total
254 amount. In 2005, the reduction in GWP was mainly due to upland crops except fallow.
255 Fallow in 2005 showed a high GWP of 4.9 Mg CO₂ ha⁻¹ yr⁻¹ and accounted for 28% of the
256 total emission. This might be due to increasing N₂O emission from green manure. On the
257 other hand, fallow showed a negative GWP per area in 2007 and reduced the total GWP.
258 Due to lower GWP also for other land uses, the overall GWP in 2007 was lowest among the
259 years.

260

261 Eco-balance Analysis

262 The eco-balance analysis was used to compare different environmental loads with farm
263 productivity (Kimura and Hatano 2007). The GWP and FSN were each compared with farm
264 income for the 3 investigated years (Figure 5). Global warming potential, FSN and income
265 outcomes under the prevailing agronomic management methods are obtained only in the
266 zone surrounded by the solid line in Figure 5. This 'feasible zone' changed among the years
267 based on farmers' land use strategies and other agronomic conditions. For instance, the
268 feasible zone for GWP and income is narrower for 2005 and 2007 compared to 2002. The
269 shapes indicate that for 2005 and 2007 higher income is only possible through an
270 accompanied increase in GWP. This relationship is particularly true for rice and soybean.
271 FSN on the other hand showed different relation to income compared to GWP. High income
272 did not coincide with high FSN in 2005 and 2007, indicating that aiming at higher income
273 would not necessary result in higher FSN environmental load. Soybean and rice manifested
274 low FSN–high income relationship (Figure 5). The area with the slashed lines in Figure 5
275 indicates reductions in GWP and FSN that will still maintain the present income level by
276 changing the land use combinations in the given agronomic management methods.

277 To ascertain the land use combinations meeting these requirements, possible land use
278 combinations were calculated using an Excel Spreadsheet by changing the land use
279 proportions from 0 to 100% at 10% increments.¹ The total number of land uses computed

280 was 8,008 and was validated using a combinatorial composition formula (Skiena 1990). Out
281 of this, the number of land uses that reduced both GWP and FSN and achieved the same or
282 higher income level was 936 for the year 2002, 901 for the year 2005 and 692 for the year
283 2007 (Table 4). The average income increased 1.17-1.26 compared to the average of each
284 year, while GWP and FSN reduced by 0.67-0.79 and 0.72-0.77, respectively. The number of
285 land use combinations meeting all requirements in the three investigated year were 290
286 (Figure 6). For almost all combinations, high proportion of wheat and abandoned area was
287 found. Even though, wheat did not have the smallest amount of FSN and showed the third
288 highest GWP in 2002, the quite stable price and that it showed no extremely high value
289 acted as an advantage. The land use with high income (rice, soybean and vegetable)
290 showed either high GWP or FSN so that their incorporation was only possible by including
291 the abandoned area, which had mitigating effect of GWP and low FSN. Abandoned area
292 was included in 259 combinations ranging from 10-40%, indicating that some mitigation
293 measure is necessary to increase income without increasing environmental load.

294 This eco-balance analysis is a holistic approach to visualize the relation of
295 environmental load and income. The present analysis showed that there is not necessarily a
296 trade-off between environmental load and income. Our analysis showed that even in such
297 case income can still be increased while reducing the GWP through different land use
298 strategies. A similar holistic approach to evaluate land uses is the ecological footprint
299 method (Liu et al. 2008). The ecological footprint calculates how much land area is required
300 to compensate the environmental load caused by human activity. But this approach does not
301 have a boundary and is rather an abstract concept. The eco-balance analysis shows
302 concrete measure to balance environmental load and benefits from farming for a given
303 region.

304 The eco-balance analysis also shows the specific characteristics of land uses in the
305 investigated region. Weak points of land uses can be found and changes in management
306 methods can be suggested. For example, paddy rice and soybean cultivation will be highly
307 recommended due to their high income and low FSN, if the GWP could be reduced.
308 Reduction of residue input or changing the timing of its incorporation (Yagi et al. 1997) would
309 be necessary for paddy rice, while addition of green manure might be recommended in case
310 of soybean. On the other hand, substitution by the government as for set aside policy

311 (Ministry of Agriculture, Forestry and Fishery 2009b) might be provided to enhance those
312 land uses with low income and low GWP and FSN like abandoned area. The fallow and
313 abandoned areas do not have any economic value in this analysis. However, increasing soil
314 quality due to green manure cultivation can increase the yield in the succeeding crop
315 (Mallory and Porter 2007). Carbon mitigation might become also of economically valuable if
316 carbon credits are applied to soil carbon sequestration.

317 The GWP, FSN and yield values in the analysis are calculated from mean values of the
318 whole region. Different soil type has different influence on greenhouse gas emission as well
319 as nitrate leaching or NH₃ emission (Sutton et al. 2000, Franzluebbers et al. 2001, Tan et al.
320 2009). A GIS based analysis considering the soil type in the land use combination analysis
321 may improve the accuracy of the analysis. Further analysis should also take into account the
322 costs for material, machinery use and labor which were not subtracted from the income at
323 present. Carbon credit may also change the relative position of each land use in Figure 4. It
324 should be kept in mind that relationships between environmental load and income are not
325 fixed – they change dynamically due to environmental condition and economic situation.
326 The present analysis is a tool to analyze the present situation and suggest optimization
327 measures.

328

329 Conclusion

330 This study showed how monitoring data can be used in eco-balance analysis to screen
331 land use combinations that address environmental as well as economic concerns. The
332 target value of environmental load or crop production can be changed according to the
333 environmental and economic condition of the investigated area. This is a relative analysis for
334 each area and monitoring data or some measure to estimate the nutrient flow must be
335 obtained. Using this analysis, incentives to choose land use combinations with lower
336 environmental load can be created.

337

338

339 Reference

340 Franzluebbers A.J. , Haney R.L., Honeycutt C.W., Arshad M.A., Schomberg H.H. and Hons
341 F.M. 2001: Climatic influences on active fractions of soil organic matter. Soil

342 Biology and Biochemistry 33, 1103-1111.

343 Freibauer A. 2003: Regionalised inventory of biogenic greenhouse gas emissions from
344 European agriculture. *Eur. J. Agron.*, 19, 135–160.

345 Fortuna A., Harwood R., Kizilkaya K., Paul E.A. 2003: Optimizing nutrient availability and
346 potential carbon sequestration. *Soil Biology & Biochemistry* 35, 1005-1013.

347 Gu J.X., Zheng X.H., Wang Y.H., Ding W.X., Zhu B., Chen X., Wang Y.Y., Zhao Z.C., Shi Y.,
348 Zhu J. 2007: Regulatory effects of soil properties on background N₂O emissions
349 from agricultural soils in China. *Plant and Soil* 295, 53-65.

350 Hokkaido Central Agricultural Experiment Station 1971: [Results of the Basic Survey on Soil
351 Fertility.] Ed. T Mori, pp. 1–019, Hokkaido. (in Japanese)

352 Intergovernmental Panel on Climate Change 1996: Revised 1996 Guidelines for National
353 Greenhouse Gas Inventories: Chapter 4. Agriculture. In *IPCC Guidelines for
354 National Greenhouse Gas Inventories Workbook (Volume 2)*. Ed. IPCC/OECD/IEA,
355 pp. 1–140. Intergovernmental Panel on Climate Change, Geneva.

356 Intergovernmental Panel on Climate Change 2007: *Climate Change 2007: The Physical
357 Scientific Basis*. Chapter 2. Eds S. Solomon, D. Qin, M. Manning, M. Marquis, K.
358 Averyt, M.M.B. Tignor, H.L. Miller, Z. Chen, Cambridge University Press, New York,
359 USA. 1-106.

360 Kimura S.D., Hatano R. 2007: An Eco-Balance approach to evaluate the historical change in
361 N loads caused by agricultural land use change at a regional scale. *Agric. Sys.*, 94,
362 165–176.

363 Kimura S.D., Liang L. and Hatano R. 2004: Influence of long-term changes in nitrogen flows
364 on the environment: a case study of a city in Hokkaido, Japan. *Nutrient Cycling in
365 Agroecosystems* 70. 271–282, 2004.

366 Kimura S.D., Mu Z.-J., Toma Y., Hatano R. 2007: An eco-balance analysis of global
367 warming potential, farmland surplus nitrogen and yield of six agricultural land uses
368 in the Ikushunbetsu Watershed. *Soil Sci. Plant Nutr.*, 53, 373– 386.

369 Kimura S.D., Hatano R. and Okazaki M. 2009: Characteristics and issues related to
370 regional-scale modeling of nitrogen flows. *Soil Science and Plant Nutrition*, 55,
371 1–12.

372 Kusa K., Sawamoto T. and Hatano R. 2002: Nitrous oxide emissions for 6 years from a gray

373 lowland soil cultivated with onions in Hokkaido, Japan. *Nutrient Cycling in*
374 *Agroecosystems* 63: 239–247.

375 Liu Q.P., Lin Z.S., Feng N.H., Liu Y.M. 2008: A modified model of ecological footprint
376 accounting and its application to cropland in Jiangsu, China. *PEDOSPHERE* 18.
377 154-162.

378 Ministry of Agriculture, Forestry and Fishery 2006: New demand and supply regulation
379 system from 2007. (Ed) Ministry of Agriculture, Forestry and Fishery, Tokyo, p1-34

380 Ministry of Agriculture, Forestry and Fishery 2009a: Price of agricultural products for 2002,
381 2005 and 2007. <http://www.tdb.maff.go.jp/toukei/toukei>

382 Ministry of Agriculture, Forestry and Fishery 2009b: Practical guideline for the measure to
383 enhancing efficient use of paddy rice fields, MAFF, Tokyo, 1-11pp (in Japanese)

384 Mallory E.B. and Porter G.A. 2007: Potato yield stability under contrasting soil management
385 strategies. *Potato yield stability under contrasting soil management strategies.*
386 *Agronomy J.* 99, 501-510.

387 Matsumoto N. 2000. Development of estimation method and evaluation of nitrogen flow in
388 regional areas. *Bull. Natl. Inst. Agro-Environ. Sci.* 18: 81–1520. (in Japanese)

389 Mikasa City 1994: New History of the Mikasa city. Committee of documenting the new
390 History of Mikasa city. (Ed.) Gyosei, Sapporo. Pp446-448. (in Japanese)

391 Mikasa City 2009: Statistics reports for the Mikasa city. Mikasa city. Mikasa.28-86. (in
392 Japanese)

393 Mu Z.-J., Kimura S.D., Toma Y. and Hatano R. 2008a: Evaluation of the soil carbon budget
394 under different upland cropping systems in central Hokkaido, Japan. *Soil Science*
395 *and Plant Nutrition* 54, 650–661.

396 Mu Z.-J., Kimura S.D., Toma Y. and Hatano R. 2008b: Nitrous oxide fluxes from upland soils
397 in central Hokkaido, Japan. *J. Environ. Sci.* 20.1312–1322.

398 Naser H.M., Nagata O., Tamura S. and Hatano R. 2007: Methane emissions from five paddy
399 fields with different amounts of rice straw application in central Hokkaido, Japan.
400 *Soil Sci. Plant Nutr.* 53, 95–101.

401 Randall G.W., Gross M.J. 2001: Nitrate losses to surface water through subsurface, tile
402 drainage. In *Nitrogen in the Environment: Source, Problems, and Management.*
403 Eds RF Follet.

404 Sapporo District Meteorological Observatory 2008: Digital reading room. Day and annually
405 climate data at Iwamizawa weather station <http://www.data.kishou.go.jp/> (in Japanese)

406 Seyfried M.S. 2003: Incorporation of remote sensing data in an upscaled soil water model.
407 In *Scaling Methods In Soil Physics*. Eds Y Pachepsky, DE Radcliff and HM Selim,
408 pp. 309–345. CRC Press, Boca Raton.

409 Skiena S 1990: *Compositions. in implementing discrete mathematics: combinatorics and*
410 *graph theory with mathematica*. Addison- Wesley, Reading, pp 60–62

411 Sutton M.A., Nemitz E., Milford C., Fowler, D. Morenoc J., San José R., Wyers G.P., Otjes
412 R.P., Harrison R., Husted S. and Schjoerring J.K. 2000: Micrometeorological
413 measurements of net ammonia fluxes over oilseed rape during two vegetation
414 periods. *Agricultural and Forest Meteorology* 105. 351–369.

415 Tan Y.S., van Es H.M., Duxbury J.M., Melkonian J.J., Schindelbeck R.R., Geohring L.D.,
416 Hively W.D. and Moebius B.N. 2009: Single-event nitrous oxide losses under
417 maize production as affected by soil type, tillage, rotation, and fertilization. *Soil and*
418 *Tillage Research* 102, 19-26.

419 Toma Y. and Hatano R. 2007: Effect of crop residue CN ratio on N₂O emissions from Gray
420 Lowland soil in Mikasa, Hokkaido, Japan. *Soil Sci. Plant Nutr.*, 53, 198–205.

421 Toma Y., Kimura S.D., Hirose Y., Kusa K. and Hatano R. 2007: Variation of emission factor
422 of N₂O derived from chemical N fertilizer and organic matter – A case study of
423 onion fields in Mikasa, Hokkaido, Japan. *Soil Sci. Plant Nutr.*, 53, 692-703.

424 Wagenet R.J. 1998: Scale issues in agroecological research chains. *Nutr. Cycl. Agroecosys.*,
425 50, 23–34.

426 World Commission on Environment and Development 1987: *Our common future*. Oxford ;
427 New York : Oxford University Press. p.1-400.

428 Yagi K., Tsuruta H. and Minami K. 1997: Possible options for mitigating methane emission
429 from rice cultivation. *Nutrient Cycling in Agroecosystems* 49: 213–220, 1997.

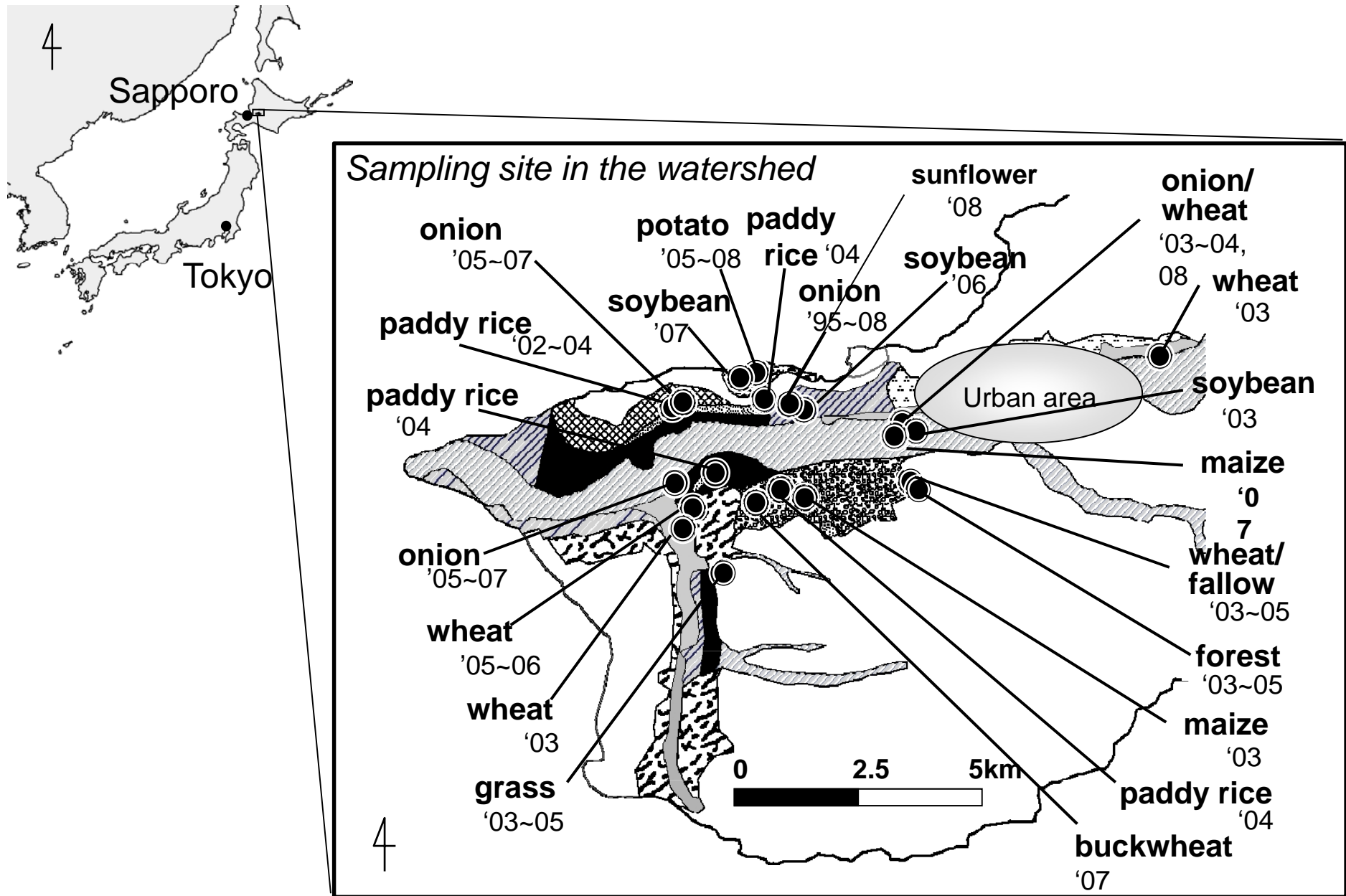


Fig. 1 Sampling sites in the Ikushunbetsu River basin of different land uses for different years. Map shows the boundary of the basin illustrated in different soil series.

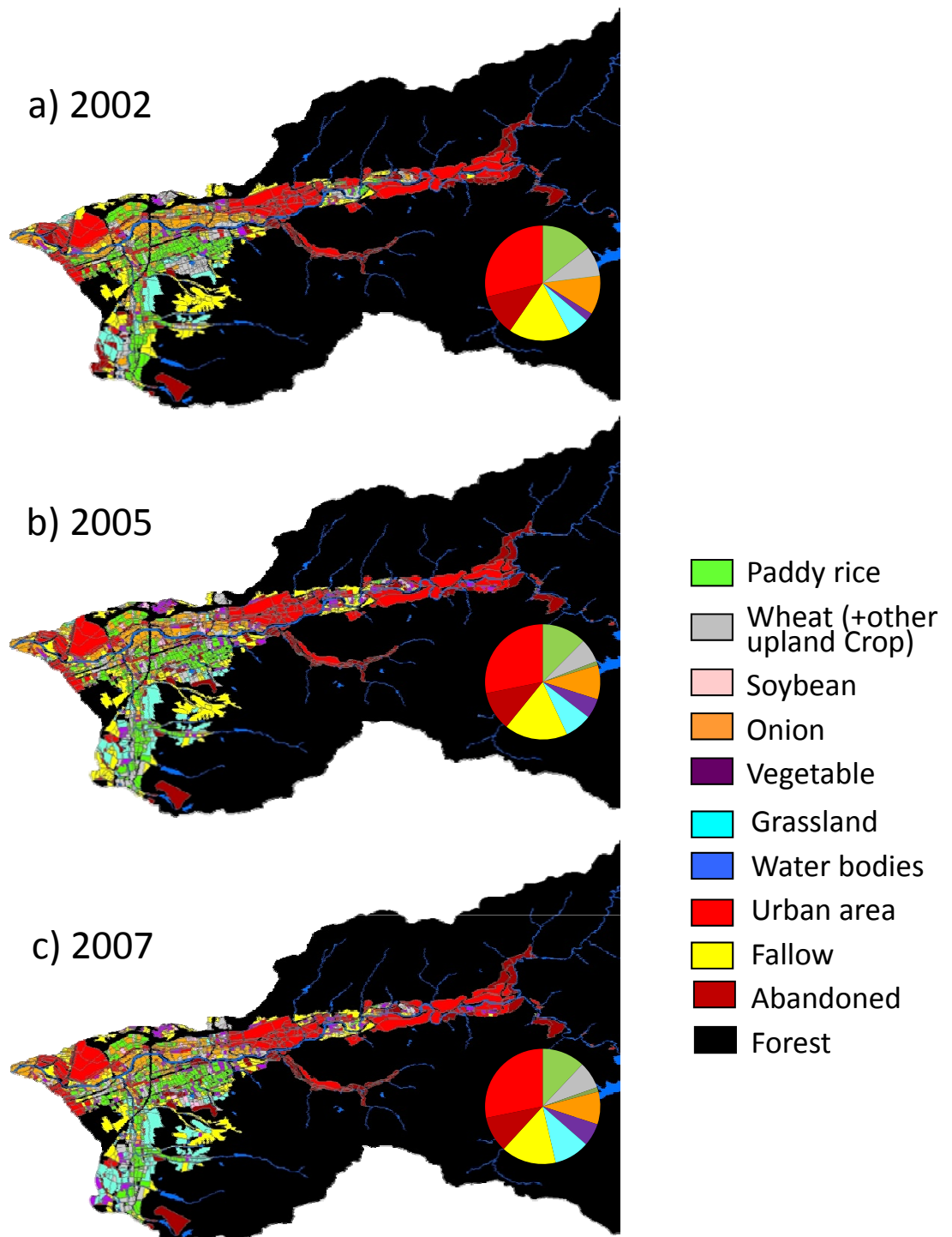


Fig. 2 Distribution of land uses in Ikushunbetsu watershed in 2002, 2005 and 2007. The Pie graph shows the proportion of each land uses.

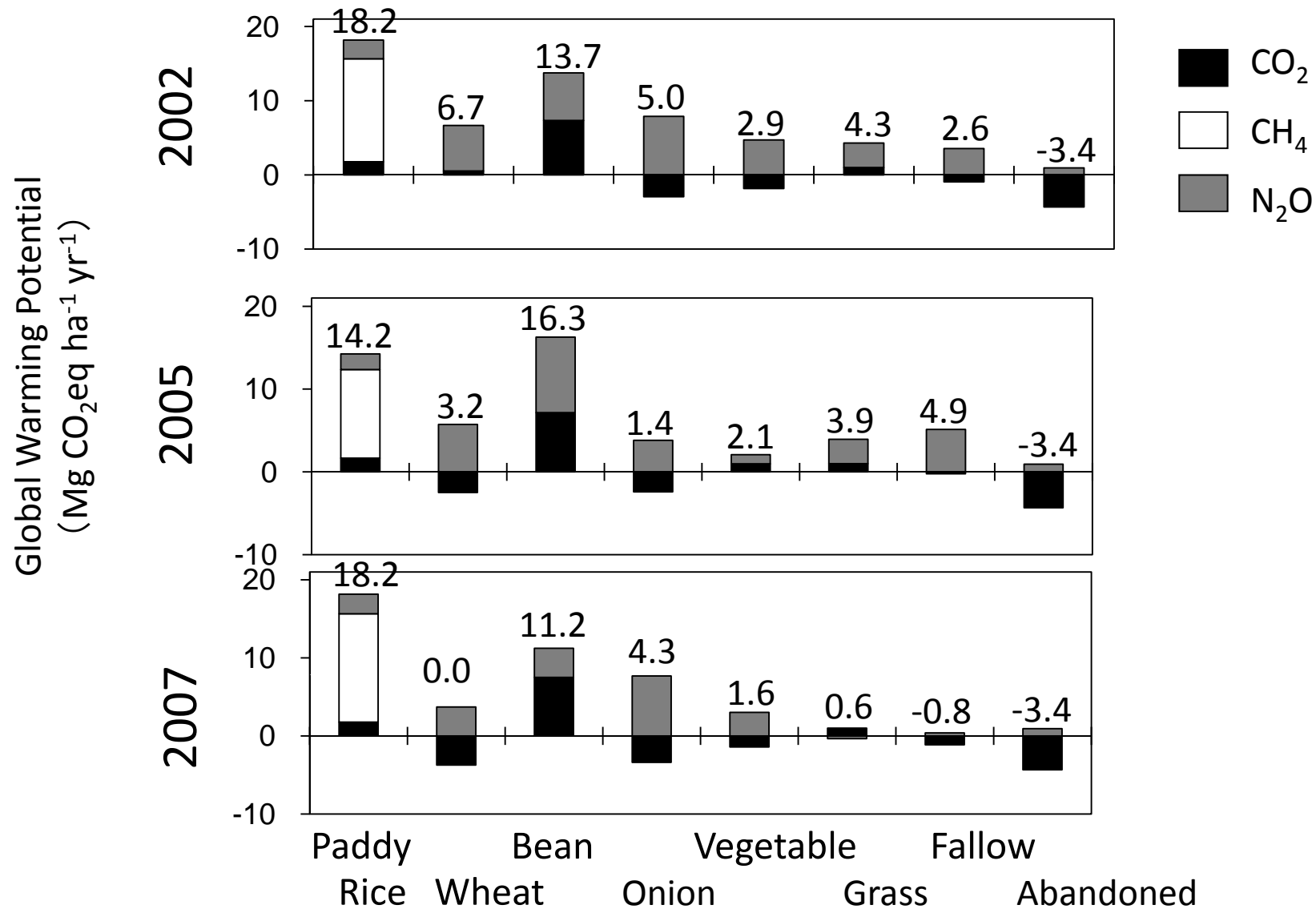


Fig. 3 Weighted mean of global warming potential of main artificial land uses in Ikushunbetsu watershed in 2002, 2005 and 2007.

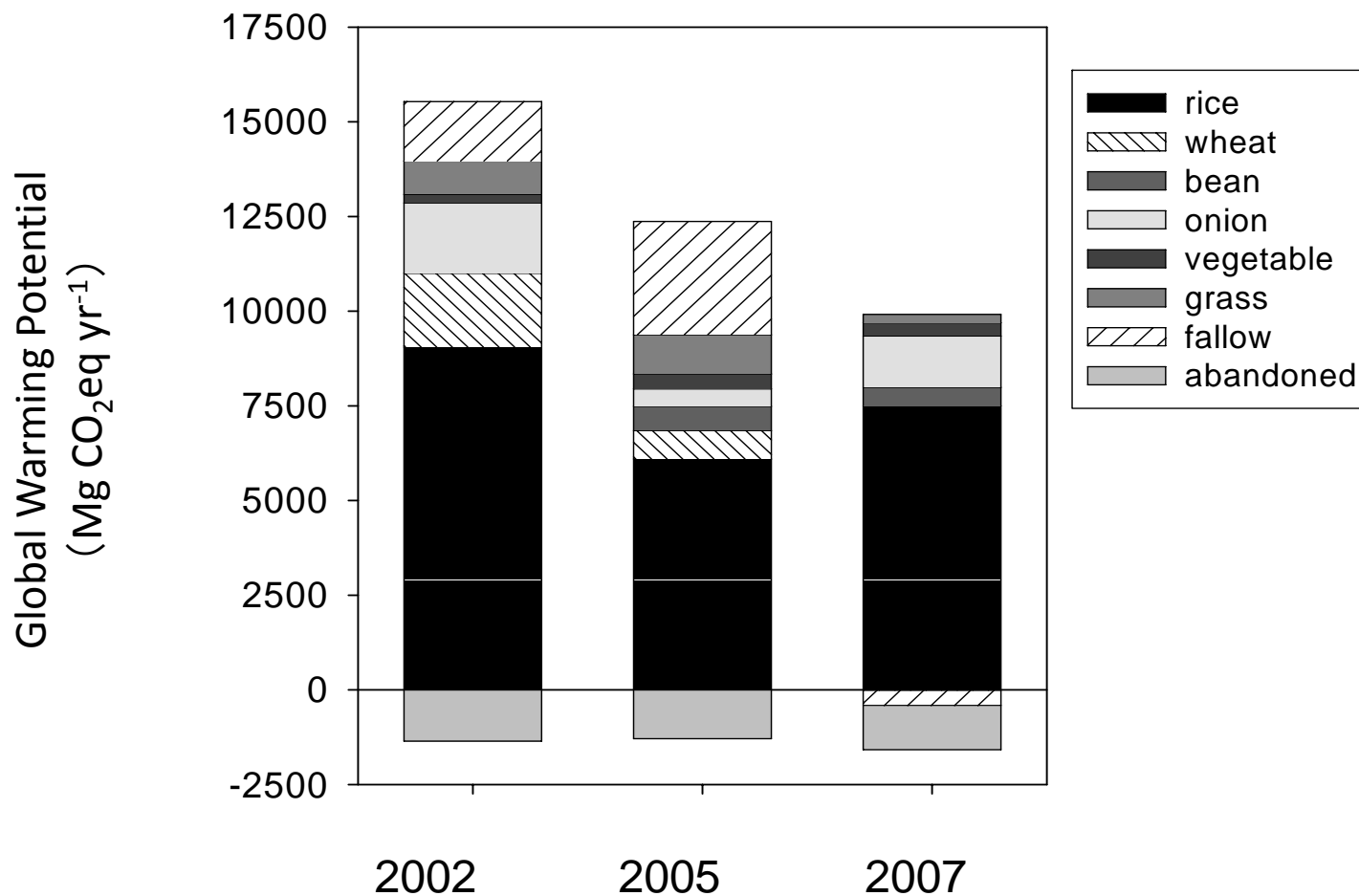


Fig. 4 Total amount of global warming potential in the region and the contribution of the main land uses in Ikushunbetsu watershed in 2002, 2005 and 2007.

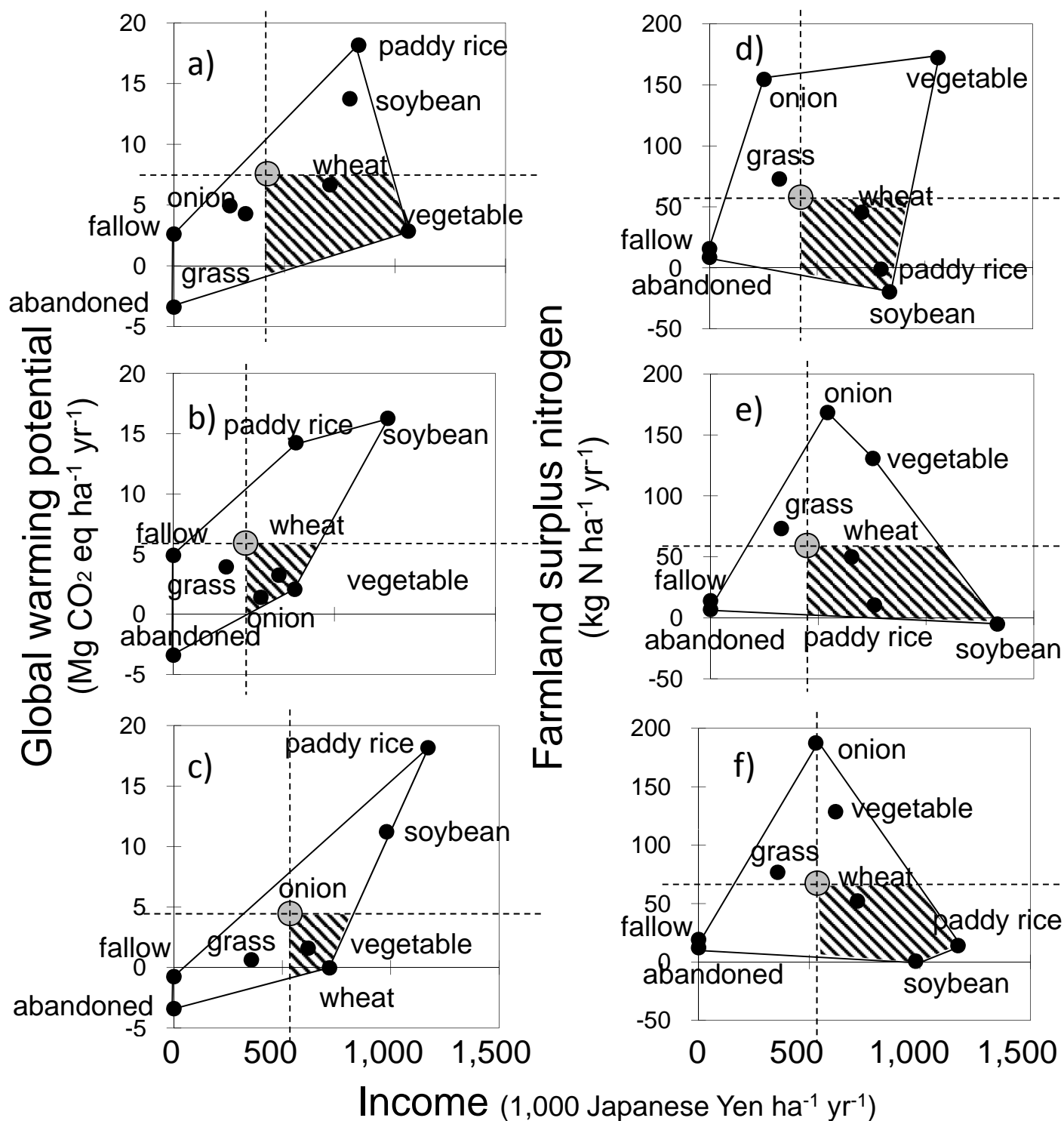


Fig. 5 Relation of global warming potential (GWP) to income for a) 2002, b) 2005 and c) 2007, and relation of farmland surplus nitrogen (FSN) to income for d) 2002, e) 2005 and f) 2007. The gray big circle represents the watershed average in each year, the black small circles represents the value if only one land use occupies 100% of the watershed. The dotted lines indicate the value of income, GWP and FSN in each year, the area with the slashed lines indicate the values of GWP and FSN which can be reduced from the present situation while maintaining the income by changing the land use combination.

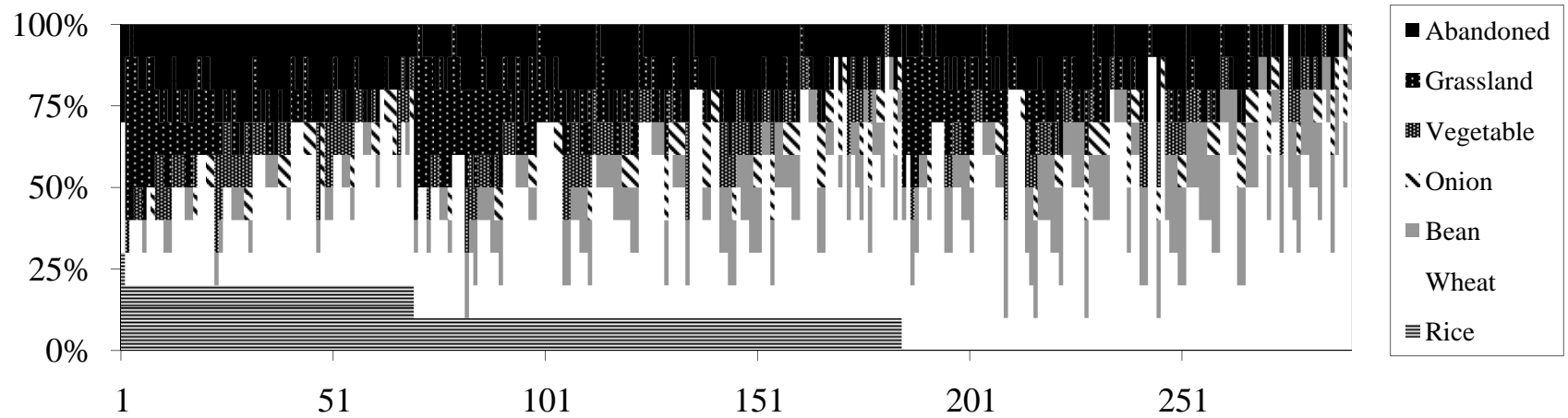


Fig. 6 Land use combinations meeting increasing the income, while reducing the GWP and FSN in all three years.

Table 1 Average Nitrogen input for the main land uses from 2002 to 2007

	paddy rice	wheat	soybean	onion	vegetable	grass	fallow	abandoned
	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)
Chemical Fertilizer	79.8 (23.5)	106.4 (61.7)	25.3 (6.2)	282.4 (121.9)	195.5 (224.7)	40.7 (9.0)	9.2 (26.6)	0.0 0.0
Manure	4.9 (18.0)	25.0 (46.3)	0.0 0.0	77.9 (181.4)	122.1 (159.5)	120.3 (26.3)	0.0 0.0	0.0 0.0
Green Manure + residue	14.3 (12.8)	19.5 (4.5)	28.2 (0.7)	114.5 (73.6)	91.1 (27.6)	16.4 (8.2)	72.1 (37.8)	72.1 (37.8)
N ₂ fixation	30.0 (15.0)	5.0 (2.5)	93.0 (46.5)	5.0 (2.5)	5.0 (2.5)	19.6 (9.8)	5.0 (2.5)	5.0 (2.5)
Deposition + Irrigation	15.4 (7.7)	7.9 (3.9)	7.9 (3.9)	7.9 (3.9)	9.4 (4.7)	7.9 (3.9)	7.9 (3.9)	7.9 (3.9)
sum	144.3	163.7	154.4	487.7	423.1	204.9	94.2	85.0

Table 2 Nitrogen in yield and farmland surplus N (FSN) in 2002, 2005 and 2007.

		paddy rice	wheat	soybean	onion	vegetable	grass	fallow	abandoned
		ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)	ave (sd)
2002	Yield	49.0 (4.3)	65.6 (15.1)	104.6 (2.5)	138.7 (23.5)	93.9 (28.5)	81.8 (20.8)	0.0	0.0
	FSN	19.5	45.5	-1.1	154.5	172.3	72.9	15.7	8.6
2005	Yield	60.8 (6.7)	62.5 (31.9)	104.6 (2.5)	132.1 (18.5)	143.9 (116.8)	81.8 (20.8)	0.0	0.0
	FSN	10.5	50.0	-5.1	168.3	130.7	73.2	15.5	6.8
2007	Yield	58.2 (7.5)	62.5 (31.9)	104.6 (2.5)	108.8 (28.9)	143.9 (116.8)	81.8 (20.8)	0.0	0.0
	FSN	14.0	52.2	0.7	187.5	128.6	76.8	20.3	12.3

Table 3 Income for the main land use in 2002, 2005 and 2007
(1,000 JPY ha⁻¹ yr⁻¹).

	paddy rice	wheat	soybean	onion	vegetable	grass
2002	835.4	705.8	795.8	253.1	1,060.2	324.0
2005	760.6	654.7	1,331.2	542.9	753.2	328.1
2007	1,172.2	717.8	980.9	529.4	619.0	357.2

Table 4 Watershed average income global warming potential (GWP), farmland surplus N (FSN) for each year at present and for the Eco Balance scenarios . No indicate the number of land use combination meeting the Eco-balance scenario criteria.

	Watershed Average			No	Scenario Result			Scenario/Year average		
	Income (,1000 Yen ha ⁻¹)	GWP (Mg CO ₂ eq ha ⁻¹)	Surplus N (kg N ha ⁻¹)		Income (,1000 Yen ha ⁻¹)	GWP (Mg CO ₂ eq ha ⁻¹)	Surplus N (kg N ha ⁻¹)	Income	GWP	Surplus N
2002年	422.7	7.6	58.0	936	524.1	6.0	41.7	1.24	0.79	0.72
2005年	448.1	5.9	59.3	901	562.4	4.4	44.1	1.26	0.75	0.74
2007年	535.9	4.5	67.4	692	627.4	3.0	52.2	1.17	0.67	0.77