Integration of biodiversity as impact category for LCA in agriculture (SALCA-Biodiversity)

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Abstract

Agroscope Reckenholz-Tänikon Research Station ART developed a method for the integration of biodiversity (organismal diversity) as an impact category of Life Cycle Assessment (LCA) for agricultural production (SALCA-Biodiversity). This method is valid for grasslands and arable crops, and integrates semi-natural habitats of the farming landscape to estimate the impact of management systems on biodiversity. First, a list of 11 indicator species groups (flora, birds, mammals, amphibians, snails, spiders, carabids, butterflies, wild bees, and grasshoppers) was established considering ecological and life cycle assessment criteria. Second, inventory data about agricultural practices with detailed management options were specified. Third, a scoring system estimated the reaction of every indicator species group regarding management options, followed by aggregation steps. In a case study, biodiversity scores for grassland along an intensity gradient as well as winter wheat with differing cropping systems were calculated. Results showed the dominant influence of management and production intensity on most indicators and management options from which large impacts on biodiversity are to be expected. The use of 11 indicator species groups allows a differential and a fairly comprehensive estimation of the impacts of the agricultural practices on biodiversity. With SALCA-Biodiversity, production systems can be compared regarding their potential impact on biodiversity, and may therefore help in making recommendations for good practices.

Introduction

Currently, the necessary integration of biodiversity and/or land use as impact category in Life Cycle Assessment (LCA) methodologies is recognized (SETAC/UNEP LCA Initiative, Milà i Canals *et al.* 2007). In this context, Agroscope Reckenholz-Tänikon Research Station ART developed a method for the integration of biodiversity as an impact category for Life Cycle Assessment (LCA) of agricultural activities (SALCA-Biodiversity, Jeanneret *et al.* 2006). Two approaches for evaluating the effects of agricultural activities (in a broad sense) on biodiversity are found in the literature: (1) biodiversity is included as a mid-point impact category in LCA like other categories, e.g. the global warming potential. This approach is essentially based on the species diversity of vascular plants and includes the impact of industry, agriculture and transport on a continent scale (e.g. Lindeijer *et al.* 1998, Müller-Wenk 1998, Köllner 2000, Milà i Canals *et al.* 2007) and also evaluates the rarity of the ecosystems and their vulnerability (Weidema & Lindeijer 2001). (2) An environmental diagnosis based on a biotope evaluation with indicators is performed (“ecological value” of farms, e.g. Frieben 1998, Brosson 1999). Our method is based on the first approach but is more detailed and is designed for use in Switzerland and adjoining regions.

On the one hand, complex biodiversity in the broadest sense of the Rio Convention cannot be totally measured as such. On the other hand, a single indicator is unlikely to be devised even in agro-ecosystems that surrogate for all other organisms with respect to reaction to farming operations (e.g. Büchs 2003). Instead, groups of indicators should be selected that are sensitive to environmental conditions resulting from land use and farming operations, and give as representative a picture as possible of biodiversity as a whole. The method presented aims at estimating and comparing the impact of agricultural management systems on biodiversity by using a set of indicator species groups. In a specific case study, results of the application of the method to several scenarios representing field management options for grassland (intensity level) and wheat (cropping system) were calculated for illustration.

Materials and methods

In the present method the choice of indicator species groups (ISGs) was made using a criteria table based on the linking of the species to agricultural activity, and general criteria such as the species distribution in the cultivated landscapes, their habitats and their place in the food chain (Jeanneret *et al.* 2006). Although recognized as a very important habitat for biodiversity supporting a high number of functions, soil and soil organisms have not been considered in this method. The reason is that impacts of agricultural practices on biodiversity in soil have not been sufficiently investigated. Then, the following ISGs were selected: flowering plants (grassland and crop flora), birds, small mammals, amphibians, snails, spiders, carabid beetles, butterflies, wild bees and grasshoppers. Furthermore, we distinguished between the overall species diversity of each species group and the ecologically demanding species (stenotopic species, red list species) in the impact estimation.

The effect of the management activities on each ISG was estimated based on information from the literature and expert knowledge. In this study, all the typical management activities of grassland and winter wheat fields such as manuring, mowing, insecticide and fungicide applications were specified with options, e.g. the type of fertiliser and the mowing period, the type of insecticide and fungicide and the application period (restricted to the Swiss farming). The impact of each management option on ISGs was rated on a scale of 0 to 5 (rating *R*, Table 1).

Table 1. Rating *R* of management option impact on the selected indicator species groups (ISG).

0:	The species group is unaffected because it does not occur in the considered agricultural habitat.
1:	The option leads to a severe impoverishment of species diversity within the species group considered and renders impossible the occurrence of stenotopic species and red list species.
2:	The option leads to a slight impoverishment of species diversity within the species group considered and renders impossible the occurrence of stenotopic species and red list species.
3:	The option has no direct effect on the species group considered.
4:	The option leads to a slight increase in species diversity within the species group considered and makes possible the occurrence of stenotopic species and red list species.
5:	The option promotes species diversity within the species group considered and makes possible the occurrence of stenotopic species and red list species.

Since agricultural habitats of the farming landscape have not the same suitability with respect to specific ISG, a coefficient ranging from 1 to 10 ($C_{habitat}$) was attributed to weight the rating of the management options for each ISG specifically. Similarly, a second coefficient from 0 to 10 ($C_{management}$) quantified the relative importance of management activities for a given habitat, e.g. grazing and mowing in grasslands, manuring and pesticide application in winter wheat, for each ISG. The final score *S* of a management option was the product of the rating of the management option *R* and the mean value of the two weighting coefficients $C_{habitat}$ and $C_{management}$ ($S = R * C_f$; where S = final rating, R = impact rating of a management option and C_f = final coefficient = $[C_{management} + C_{habitat}]/ 2$). In case of management activities repeated during the year (e.g. mowing) an annual average was calculated when the ISG can recover from one period to another, or the most negative period was considered in case of a permanent damage. The final ISG score of a given agricultural habitat was calculated as the mean *S* over the management options. Furthermore, ISG scores were aggregated to a biodiversity score taking into account rules of trophic relations between ISGs. Comparison of management scenarios can then be made at field level first but as ratings and coefficients were also defined for semi-natural habitats, ISG and biodiversity scores can also be calculated at farm level by aggregation of the scores obtained for single agricultural habitats (except vegetable, fruit and grape crops).

To illustrate use of the method and discuss results of impact calculation on biodiversity and particular ISGs, realistic scenarios of grassland and winter wheat management systems for the Swiss lowlands were defined (Table 2, Nemecek *et al.*, 2005). Scenarios addressed a large intensity gradient for grasslands ranging from one utilization and no fertilization (2.7t DM/ha and year) to five utilizations and fertilizer applications (11t DM/ha and year). Similarly, various cropping systems were considered for winter wheat along a gradient of production intensity (3.5t DM/ha and year – 5.8t DM /ha and year).

Table 2. Management characteristics and production of grassland and winter wheat systems used to test the method of impact calculation on ISGs.

Grassland systems (hay production)		Management characteristics and production
A	Intensive grassland	5 cuts/year, fertilised with slurry; 11t DM/ha
B	Fairly intensive grassland	4 cuts/year, fertilised with slurry; 9t DM/ha
C	Low intensive grassland	3 cuts/year, fertilised with solid manure; 5.6t DM/ha
D	Extensive grassland	1 cut/year; no fertilisation; 2.7t DM/ha
Winter wheat systems		
E	Conventional production	5.8t DM/ha
F	Integrated production– intensive	5.5t DM/ha
G	Integrated production – extensive	4.5t DM/ha
H	Organic production	3.5t DM/ha

Results

Compared results of grassland and winter wheat systems suggested that the crop was on average less suitable for most of the ISGs (Table 3). The transition from conventional and intensive integrated winter wheat systems (scenario E and F) to extensive (integrated) and organic production (scenario G and H) did not reveal the spectacular increase of scores occurring from intensive and fairly intensive (A and B) to low intensive and extensive grassland systems (C and D). However, conventional and integrated winter wheat systems (E and F) exhibited slightly higher aggregated biodiversity scores than the most intensive managed grasslands (A and B). This difference was mainly due to higher scores obtained by the crop flora (compared to the grassland flora) and the carabid beetles as shown by detailed ISG results. The highest scores were calculated for butterflies in extensive grassland and the crop flora in winter wheat, 36.0 (D) and 17.3 (H), respectively, and the lowest for amphibians in intensively managed grassland and winter wheat, 0.8 (A and B) and 1.4 (F), respectively. For a rough comparison, the aggregated biodiversity score obtained by a hedgerow with a standard management (result not shown), as a typical semi-natural habitat of the agricultural landscape, is about 21, and varies between 11 and 38 depending on ISG.

Calculated for the range of grassland types, scores definitely increased with decreasing management intensity (scenarios A to D) for the aggregated biodiversity, the overall species diversity of most of the ISGs and for the ecologically demanding species (Table 3). Scores for ecologically demanding species were slightly lower than those of overall species diversity. An obvious inflection point occurred between 4 and 3 cuts/year (fairly intensive and low intensive grasslands) and a change of the manure form. Indeed, aggregated biodiversity scores increased by 0.2 from intensive to fairly intensive, by 7.4 from fairly intensive to low intensive. Nevertheless, scores increased by an additional 7.5 from low intensive to extensive grasslands. Snails were an exception to this pattern, the largest difference taking place between low intensive and extensive grassland (93.9% increase). No fertilization at all was then more important than the fertilizer form for snails. Extensive grasslands obtained higher biodiversity scores than low intensive grasslands except for mammals which do not take advantage of one of both types. The largest difference in percentage occurred between fairly intensive and low intensive grasslands for the amphibian special life phase but at a very low score level (aquatic life phase, 0.8 to

2.9, 262.5%). The highest scores were obtained by butterflies in extensive grasslands (36.0 for the overall diversity and the ecologically demanding species), followed by grasshoppers and wild bees.

Regarding winter wheat systems, organic production obtained the highest aggregated biodiversity and ISG scores. Aggregated biodiversity scores increased stepwise slowly, from the intensive integrated production (reference scenario), to the organic production, i.e. F to E, 0.2 (2.7%), E to G, 0.7 (9.1%), G to H, 0.3 (3.6%). Interestingly, spiders and birds showed the highest increase of scores from conventional (E) to extensive integrated production (G) with 2.3 (28%) and 0.9 (17%), respectively, and 2.3 (28.8%) for ecologically demanding spider species. The lowest scores were calculated for amphibians, snails and mammals, for which change of production system only causes minor changes of scores. Conventional production obtained a slightly higher score for wild bees at a relatively low level (5.2), however. For grassland flora, butterflies and grasshoppers, no scores were calculated because crop fields have no or negligible importance as habitat for these ISGs.

Table 3. Results of SALCA-Biodiversity for grassland and winter wheat systems. ISG and biodiversity scores are given per ha cultivated crop. Scores of grassland system (A) and winter wheat system (F) are set as reference scores. Scores with the same format are considered similar to the reference (95%< score <104%). Scores underlined are considered better than the reference (105%< score <114%). Scores double underlined and bold are considered much better than the reference (score >115%). Theoretical minimum score is 1 and maximum 50. No scores means no relevance for the considered system.

	Biodiversity scores							
	Grassland				Winter Wheat			
Production systems	A	B	C	D	E	F	G	H
	Overall species diversity							
Aggregated[1]	6.2	6.4	**13.8**	**21.3**	7.7	7.5	8.4	**8.7**
Grassland flora	3.7	3.9	**11.4**	**18.5**				
Crop flora					15.2	15.1	16.0	17.3
Birds	6.4	6.7	**13.8**	**22.0**	5.3	5.0	**6.2**	**6.4**
Mammals	7.3	7.3	**11.1**	**11.1**	4.6	4.6	4.6	4.6
Amphibians	2.1	2.1	**5.2**	**9.5**	1.7	1.7	1.8	1.8
Snails	5.4	5.6	5.8	**11.3**	2.2	2.2	2.2	2.2
Spiders	9.1	9.3	**15.8**	**22.4**	8.2	8.0	**10.5**	**10.7**
Carabid Beetles	7.0	7.4	**13.6**	**21.0**	10.9	10.6	11.7	11.9
Butterflies	6.8	7.0	**20.0**	**36.0**				
Wild Bees	7.4	7.6	**18.6**	**23.0**	5.2	4.9	5.0	4.8
Grasshoppers	6.9	6.9	**19.4**	**33.1**				
	Ecocologically demanding species							
Amphibians	0.8	0.8	**2.9**	**4.8**	1.5	1.4	1.6	1.6
Spiders	8.9	9.0	**15.3**	**21.6**	8.0	7.8	**10.3**	**10.5**
Carabid Beetles	7.0	7.3	**13.4**	**20.6**	10.6	10.1	11.2	11.3
Butterflies	6.7	6.8	**19.4**	**36.0**				
Grasshoppers	6.8	6.8	**19.3**	**32.9**				

[1]ISG scores are aggregated taking into account rules of trophic relations between indicator species groups.

Discussion

Aggregated biodiversity and ISG scores suggest that biodiversity is on average less impacted by grassland than by winter wheat systems. This can be explained by a higher wide-ranging disturbance level usually occurring in crop fields compared to grasslands. However, the difference between grassland and winter wheat mainly occurred in less productive systems, i.e. in extensive and low intensive grassland compared to extensive integrated or organic production of winter wheat. The reason is that a crop field remains a monoculture with low habitat diversity even in extensively managed systems. In the contrary, grasslands with extensive management usually encompass large habitat diversity by first providing species-rich vegetation. The spectacular scores obtained by most of the IGSs in the extensive grassland system showed the importance of this management for biodiversity. The scores distinctly decreased in two steps, first from extensive to low intensive grassland, and then from low intensive to fairly intensive and intensive grassland, demonstrating that impacts occurred due to the increasing number of cuts (3 to 4-5 cuts/year and 1 to 3 cuts/year), which directly affects the habitat, and the fertilisation form. The high scores for butterflies, grasshoppers and wild bees in extensively used grassland were mainly due to the high habitat coefficients attributed to grassland habitats reflecting their importance for all three ISGs in the agricultural landscape as potential habitat. Detailed analysis of results also showed that dramatic effect can be observed by increasing the management intensity and increasing the production level accordingly, from low intensive to fairly intensive grasslands (115.6% decrease of the aggregated biodiversity score).

Although at a lower level than extensively managed grassland, organic production obtained the highest scores for the aggregated biodiversity and ISG scores among winter wheat systems. This is in accordance with the management techniques that usually take place in this system, and their impact on ISG, i.e. no application of chemical-synthetic pesticides and lower fertilization rate. Compared to its extensive form, the intensive integrated production negatively affected in particular spiders and birds because of the use of unselective pesticides and the more frequent disturbances involved for usual farming operations.

Conclusion

Although limited to agriculture, the method SALCA-Biodiversity represents an important step toward integration of biodiversity in LCA. With SALCA-Biodiversity, impacts of the most important agricultural practices and choices of farmers on biodiversity can be recognized. Impacts of agricultural practices on several indicator species groups of the above-ground habitats that take place in grassland and crop systems can be compared and recommendations can be made accordingly. Results showed that impacts are specific to indicator species groups and cannot reliably be derived from one single indicator.

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