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Assessing the intensity of temperate European agriculture at the landscape scale

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Abstract

The intensity of agricultural production was assessed in 25 landscape test sites across temperate Europe using a standardised farmer questionnaire. The intensity indicators, nitrogen input (to arable crops and to permanent grassland), density of livestock units and number of pesticide applications (herbicides, insecticides, fungicides and retardants), were recorded and integrated into an overall intensity index. All three components were needed to appropriately characterise the intensity of agricultural management. Four hypotheses were tested. (i) A low diversity of crops is related to higher intensity. The contrary was observed, namely because diverse crop rotations contained a higher share of crops which are more demanding in terms of nitrogen and of plant protection. (ii) Intensity decreases when there is more permanent grassland. This was confirmed by our study. (iii) Large farms are managed more intensively. There was no relation between farm size and intensity. (iv) Large fields are managed more intensively. There was a tendency towards higher nitrogen input and livestock density in landscapes with larger fields but only a few of the results were statistically significant. The aggregated overall intensity index was of limited usefulness mainly because of limitations in interpretability.

Keywords: Nitrogen; Livestock density; Pesticide; Intensity index; Crop diversity; Grassland; Farm size; Plot size; Biodiversity; Water quality

1. Introduction

The intensity of agricultural production in Europe strongly increased during the 20th century, resulting in higher yields and a secure supply of the population with food at affordable prices. In the last decades, however, environmental damage caused by agriculture increased as well and is usually imputed to high intensity levels of industrialised agriculture (Stoate et al., 2001; Baldock et al., 2002).

Environmental damage such as water and air pollution and the loss of biodiversity occur at the landscape level. Measuring the intensity of agricultural management at the landscape level is, however, not straightforward and often conceptually not clear. Aspects of agricultural management and landscape properties are sometimes intermingled (Matson et al., 1997; Wardle et al., 1999; Zechmeister and Moser, 2001). For example, the size of agricultural fields are often used as an indicator of agricultural intensity (Bühler-Natour and Herzog, 1999). Similarly, the number of crops in the rotation are cited as an indicator for potentially higher biodiversity and/or for reduced intensity (EU, 1999). It is questionable as to whether these can be considered as correct assumptions.

In the context of a European research project, we were given the task to provide a framework for the quantification of agricultural land-use intensity at a regional scale for selected landscapes across temperate Europe. In this paper, we detail the methods

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and results. Moreover, we want to contribute to the clarification of the concept of agricultural intensity by testing a number of hypotheses which are often used – implicitly or explicitly – in conjunction with the intensity of agricultural management:

Hypothesis 1. A low diversity of crops (short crop rotation) indicates high intensity of agricultural management (Desender and Alderweireldt, 1990; McLaughlin and Mineau, 1995; Bockstaller et al., 1997; Matson et al., 1997; EU, 1999).

Hypothesis 2. A higher share of permanent grassland indicates lower intensity of agricultural land use (Burel et al., 1998; Chamberlain et al., 2000).

Hypothesis 3. Large farm holdings manage the land more intensively (EU, 1999).

Hypothesis 4. Increasing size of agricultural fields indicates higher intensity of agricultural management (Burel et al., 1998; Bühler-Natour and Herzog, 1999; Jonsen and Taylor, 2000; Weibull et al., 2000; Ouin and Burel, 2002).

The method is based on an operational definition of agricultural intensity and relies on variables that are considered as drivers of biodiversity, that directly influence water quality and which can be easily collected from farmer interviews. We propose three intensity indicators and an overall index.

1.1. Framework for the assessment of the intensity of agricultural management

Increasing the intensity of agricultural production in terms of increased yields per area of land and per unit of input (labour and capital) is a necessity to feed the growing world population. This needs to be done in a sustainable way, balancing socio-economic and environmental requirements (e.g. Tilman et al., 2002). If resources are used efficiently and inputs and outputs are matched (De Wit, 1992), undesirable environmental effects can be minimised.

Land-use intensity is best defined as output per unit of land at a given time (Turner and Doolittle, 1978; Shriar, 2000) or the production per operational unit (Hayami and Ruttan, 1985). Agricultural outputs are highly diverse and include the food tonnage of a variety of crops, caloric or protein value, fibre and other non-food products, etc. Assessing their monetary value would make these outputs comparable; however, farm gate prices vary considerably both temporally and between countries (Shriar, 2000). Alternatively, therefore, agricultural land-use intensity can be assessed by quantifying agricultural inputs that aim to increase productivity. Labour, skills and capital, which materialise through, for example, mechanisation, fertiliser and pesticide inputs, can both be measured and also used as surrogates for intensity (Brookfield, 1972; Turner and Doolittle, 1978; Lambin et al., 2000; Shriar, 2000; Kerr and Cihlar, 2003). It is hypothesised that these inputs will increase the agricultural output.

At the landscape scale (regional level), the crop rotation is the appropriate level for the quantification of production activities (Van Ittersum and Rabbinge, 1997). At this scale, the intensity of agricultural production per se should be distinguished from landscape composition (the share of different land-use types) and landscape configuration (the spatial organisation of the landscape). In the process of mechanisation and industrialisation of agriculture during the last decades, the intensity of production in terms of inputs was increased and the landscape was modified through farm re-allotments and land re-allocations. Because both processes occurred simultaneously, they are sometimes confounded under the label of intensification. For an analysis of causal relationships, it is helpful, however, to distinguish the two.

There is a range of potential indicators of agricultural intensity. We selected intensity indicators (inputs) which are known to affect the environment, namely biodiversity and water quality. Increasing fertiliser inputs can cause water quality problems (Wolf et al., 2005) and have both direct and indirect (e.g. positive correlation between increased nitrogen use and plant diseases) effects on biodiversity (Wilson et al., 1997; Joyce, 2001; Vickery et al., 2001). Livestock affects the air quality through ammonia emissions (e.g. Reidy and Menzi, 2004) and acts on biodiversity through the many possible ways in which grasslands may be utilised by ruminants and through the amount and quality of organic manure produced (Flisch et al., 2001). Pesticides actually target certain species and species groups, affect non-target organisms (Mineau, 1988; Chiverton and Sotherton, 1991; McLaughlin, 1994; Moreby et al., 1994; Greig-Smith et al., 1995) and may accumulate in soils and water (Schnorr, 1991).

Policy makers need indicators to evaluate the impact of agriculture on the environment. Several countries and organisations have therefore started to develop agri-environmental indicators. Most of them consider inputs as measures for agricultural intensity. The OECD DPSIR-model (OECD, 1994, 2000, 2001) has a wide acceptance, and is used as a framework for numerous concepts of environmental indicator systems. For an overview on national and supra-national initiatives, see Wascher (2000). Some examples of national agro-environmental indicators are given by Daniel et al. (2003), Garcia Cidad et al. (2003). European examples are the IRENA (2005) and EIONET (2003) initiatives (see the homepage of the European Environmental Agency for more information).

Reducing the many intensity indicators into preferably just a single index would facilitate communication. Giller et al. (1997), Shriar (2000), Donald et al. (2001), Decaëns and Jiménez (2002) and Kerr and Cihlar (2003) all developed intensification indices, which aggregated the individual indicators into a single value. Their aims were to rank the systems along an intensity gradient as well as to detect relationships between biodiversity and the index.

2. Material and methods

2.1. Investigation areas

In the EU-commissioned research project "Vulnerability of biodiversity in the agro-ecosystem as influenced by green veining and land-use intensity", 25 landscape test sites (LTS) of 5 km × 5 km each were selected in France (3 LTS), the Netherlands (4 LTS), Belgium (4 LTS), Switzerland (3 LTS), Germany

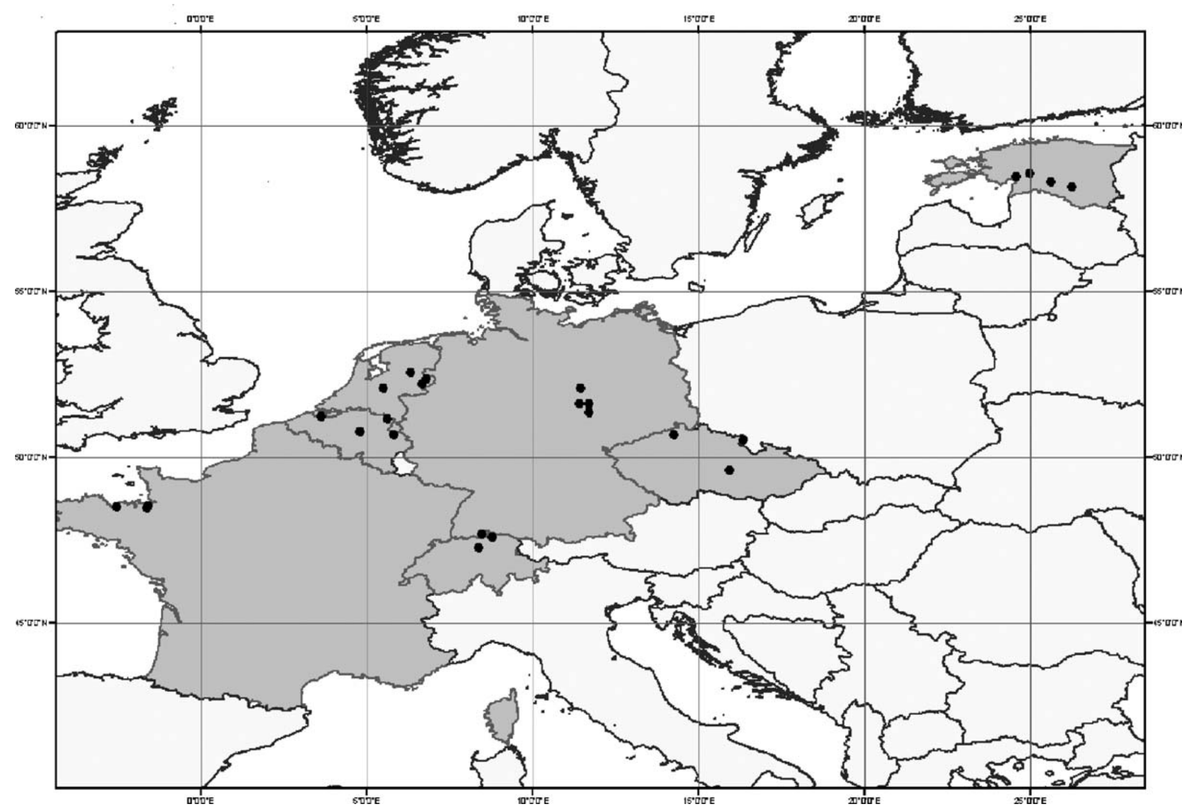


Fig. 1. Location of the landscape test sites.

(4 LTS), Estonia (4 LTS) and the Czech Republic (3 LTS) (Fig. 1). The LTS were predominantly agricultural (between 2 and 60% of non-agricultural land use), flat (thus potentially suitable for intensive arable agriculture), homogeneous and representative of a larger area. By independently selecting gradients of both, land-use intensity and the share of semi-natural habitats, a multitude of combinations of those two factors were created (Bugter et al., 2001). As the test sites were chosen deliberately to span gradients and were not selected randomly, they are neither representative for the agricultural landscapes of their respective countries nor for the link between land-use intensity and share of non-productive area. They must be regarded as case study areas which span along a gradient of land-use intensity combined with a gradient of the share of semi-natural habitats.

2.2. The questionnaire

In a supra-regional study, which extends over several administrative units, compiling existing statistical data from various sources is problematic due to the lack of standardisation during data collection. Moreover, the scale of national statistical data is not adapted to the scale investigated in the research project and would not have allowed to distinguish intensity levels of landscape test sites within individual countries. Therefore, the indicators had to be measured at the different sites through farmer interviews.

A standardised questionnaire was elaborated and tested in Estonia, the Netherlands and Switzerland, and then adapted accordingly for the interviews in all countries. The questions and answers did not relate to one particular year or individual plot but to the farmers' average practice. Table 1 summarises the indicators and their related definitions.

In each LTS, 10 or more randomly selected farmers were interviewed who together managed at least 10% of the core area (the inner 16 km^2) of the LTS. In some LTS, however, the areas managed per farm were so big that no 10 farms existed, and only 2–4 farmers could be interviewed; 211 interviews were thus conducted in total. The data were cross-checked for consistency. Mean indicator values per LTS were computed by weighting the indicators of individual farms with their utilised agricultural area (UAA), then averaging. The number of pesticide applications was weighted by the area of arable land only. Mean values and standard deviations were sent to the local partners to assess plausibility. Outliers were double-checked and, if necessary, corrected. The overall intensity index was calculated by normalizing the three indicators nitrogen input, livestock density and pesticide input according to Legendre and Legendre (1998), then averaging them (Eq. (1)).

$$I = \frac{\sum_{i=1}^{n} (y_i - y_{\min})/(y_{\max} - y_{\min})}{n} \times 100 \quad (1)$$

where I is the overall land-use intensity index, y_i the observed value, $y_{\min}$ the minimum observed value, $y_{\max}$ the maximum observed value and n is the number of individual indicators.

In order to extract the field size, the land cover of the LTS was mapped and digitised from recent geo-referenced aerial photographs. For the estimation of the duration of the vegetation period, its start and end day were determined from the European

Table 1
Land-use intensity indicators and context information as defined in the questionnaire

Indicator	Sub-indicator	Unit	Justification	Definitions	Limitations
Nitrogen input to UAA		kg N/ha	High nitrogen inputs result in eutrophication of the soil, affect the composition of the flora and increase the risk of nitrate leaching to groundwater	Mean value of the N-input to arable crops and the N-input to permanent grassland, weighted by the area of arable land and the area of permanent grassland, respectively (see sub-indicators). Nitrogen content of mineral fertiliser according to farmers' indications. Nitrogen content of organic and waste fertiliser according to farmers' indication, to local tables of fertiliser content or to Flisch et al. (2001). Atmospheric deposition according to www.emep.int. UAA: utilised agricultural area (cropland and permanent grassland) excluding forest and farm building area	The main limitation is the estimation of quantity and quality of organic fertiliser. Often, the farmer found it difficult to indicate the exact quantity of manure and slurry that is applied and the dilutions of slurry with water may not have been recorded. Analysis of the nitrogen content of organic fertiliser at the moment of fertilisation was hardly ever available
	N-input to arable crops	kg N/ha		Nitrogen input given to the two major crops of the rotation. The area under crop rotation included rotational grassland and interrupted grassland (ploughed and re-sown every 3–6 years)	
	N-input to permanent grassland	kg N/ha		Nitrogen input given to the permanent grassland. The area under permanent grassland was defined as UAA which is not ploughed during the crop rotation and which has been there for more than 10 years	
Livestock density		LU/ha	Increased density of animals lead to high nitrogen and phosphorous inputs, affect the composition of the flora and lead to high ammonia emissions	One fertiliser livestock unit (LU) equals one adult milk cow which yields 5000 l milk/a. LU was increased/decreased by 10% for every 1000 l more/less average milk production. Other (smaller/younger) animals were counted and converted with factors (Flisch et al., 2001 or local tables if available) to fertiliser LU in order to have a single measure for the animal density on the UAA. For pigs and poultry, not the number of animals but the number of places occupied were counted and converted with factors	The transformation of numbers of animals to fertiliser livestock units was based on coarse factors, which take neither the quantity nor the type of fodder into account

Table 1(*Continued*)

Indicator	Sub-indicator	Unit	Justification	Related definitions	Limitations
Pesticide use			A high number of pesticide applications increase the risk of water pollution and may affect biodiversity	The sum of synthetic herbicide, insecticide, fungicide and retardant applications (see sub-indicators) on the two major crops of the rotation	There are many pesticides with different active substances. This complexity as well as the variability in the quantities applied and in the timing of the applications was neglected and only the number of applications was recorded
	Herbicide	No. of applications	Herbicides can reduce the floristic diversity	Number of herbicide applications on the two major crops of the rotation	
	Insecticides	No. of applications	Insecticides may directly affect arthropods and other organisms	Number of insecticide applications on the two major crops of the rotation	
	Fungicide	No. of applications	Fungicides may affect non-target organisms, namely soil fauna	Number of fungicide applications on the two major crops of the rotation	
	Retardants	No. of applications	Retardants/growth regulators are phytohormones, which can have an impact on the non-target flora	Number of retardant applications on the two major crops of the rotation	
Overall land-use intensity index				Indicators on nitrogen input to UAA, LU density and pesticide use were normalized on a scale of 0–100 and averaged to an integrated land-use intensity index (according to Legendre and Legendre, 1998)	

UAA: utilised agricultural area; LU: livestock unit.

Fourier-Adjusted and Interpolated Normalized Difference Vegetation Index (EFAI-NDVI) dataset (Stöckli and Vidale, 2004). The EFAI-NDVI is a vegetation phenology dataset for the years 1982–2001, derived from satellite remote sensing over Europe. NDVI is a normalized ratio calculated from red and near-infrared wavelengths and exploits the spectral properties of land surface vegetation. NDVI time-series of the nearest pixel for each LTS were extracted. From these, a threshold of 30% in the range between the minimum and maximum yearly NDVI value was set, and for each year the starting and ending dates were determined where the EFAI-NDVI time-series crossed this threshold. The dates were averaged over the period between 1982 and 2001.

A correlation and a factor analysis were conducted for the seven indicators (at farm level, see below) to check whether the indicators were reasonably independent, whether some could be discarded and if one indicator would be of overriding statistical power to explain the overall intensity on the investigation sites.

Data analysis was conducted at two levels. Hypotheses 1–3 could be tested at the farm level. The farms of all LTS of each country were pooled and with a Kruskal–Wallis ANOVA we tested whether the indicator values of individual countries were at different orders of magnitude. We then conducted a correlation analysis between the farming intensity indicators – including the intensity index – and crop diversity, the share of permanent grassland and farm size. Hypothesis 4 could only be tested at the level of LTS because data on field size were extracted from aerial photographs and not assigned to individual farms. Therefore, field size was available only as average value for the entire LTS, but not for individual farms. The LTS were pooled into two distinct groups: (i) the former eastern bloc states consisting of all LTS of Estonia, the Czech Republic and (former eastern) Germany and (ii) the western European countries consisting of all LTS of Belgium, France, the Netherlands and Switzerland. As for individual countries, we used a Kruskal–Wallis ANOVA to test whether the indicator values of the two groups of countries were in different orders of magnitude. A correlation analysis was then conducted between the average field size and the area weighted average values of the intensity indicators and the intensity index per LTS.

For the correlation analyses, outliers (outside the range of ±2 standard deviations) were identified and subsequently the analyses were repeated with and without the outliers. Outliers that increased the correlation to a significant level were eliminated. Significances were calculated at $p \leq 0.05$ (Pearson). A modified Bonferroni procedure was used to control type 1 error ($\alpha = 0.05$) (Jaccard and Wan, 1996). The statistical analyses were carried out with the software STATISTICA 6.

3. Results and discussion

The following remarks on: (i) the difficulties we encountered conducting cross-country interviews, (ii) the problem of weighting indicators and (iii) the problem of geographical gradients enable a more accurate assessment of the validity of the results presented thereafter.

(i) Conducting interviews across different countries. Because insight cannot only be gained from the successful but also from the more problematic areas of a project (Knight, 2003), it may be of interest to mention some of these. For example, the original questionnaire contained a request for the 'Number of cuts of mown grassland'. The answers' plausibility was tested by relating them to the indicator 'N-input on grassland' because a positive correlation between those two indicators can be expected (Dietl, 1986; Niggli et al., 1993; Flisch et al., 2001). This was not the case and further investigations with the local partners led us to conclude, that the questionnaire was not adapted to capture the wide diversity of mowing and mixed mowing–grazing systems. Therefore, this indicator had to be skipped.

This problem had not become obvious after the test interviews conducted in Estonia, the Netherlands and Switzerland as it only rose in some of the other countries. However, the test interviews prevented the occurrence of other problems. For example, it became clear that permanent and rotational grassland needed to be precisely defined. It also became evident that we could not use a single crop (e.g. wheat) as a reference crop and compare yields and inputs because there was no crop which was cultivated in all LTS. Furthermore, it proved helpful to elaborate an electronic (EXCEL based) questionnaire and to implement some automated cross-reference computations. Above all, it was extremely important to distribute a detailed protocol with explanations to all questions in order to standardise the interviews as much as possible (see Table 1). These precautions allowed us to produce a consistent set of land-use intensity indicators for the countries under investigation and which were generally appropriate for temperate Europe.

(ii) Weighting the indicators. It is unlikely that all indicators have the same importance for the assessment of intensity. We were not aware, however, of objective and reproducible criteria to weight some indicators more than others. They were therefore all given the same weight. For particular purposes (e.g. relating intensity of agricultural land use to specific biodiversity indicators), there may be grounds to weight the indicators separately or to only use selected indicators.

(iii) Geographical gradient. First exploratory analysis yielded a correlation between the LTS geographical position and intensity indicators, particularly between longitude and nitrogen input. The potential yield level is mainly dependant on solar radiation and temperature (Van Ittersum and Rabbinge, 1997). We hypothesised that a longer vegetation period – which is governed by radiation and temperature – might allow for a higher intensity of production. Therefore, the indicator and index values were corrected for duration of the vegetation period in order to yield 'intensity per day' values. However, the relative differences between the LTS remained unchanged and we concluded that for the analysis conducted thereafter, the geographical gradient could be disregarded.

Note that all indicators used in this study are suitable to assess the land-use intensity in the temperate zone only. It is assumed that each year one crop is cultivated, eventually with an intermediate crop. Other systems to describe the intensity of agricultural management often consider the possibility of cultivating several crops per year or take into account a fallow of one or several years.

3.1. European agriculture and its intensity are highly diverse

In Table 2, the general characteristics of the farms, averaged for the landscape test sites, are summarised. Most of them were dominated by mixed farming systems (15 LTS), followed by cattle farms (6 LTS), arable farms (3 LTS) and 1 LTS with predominantly pig farms. Cereals were one of the two major crops in 20 LTS, followed by rotational grassland (15 LTS) and by maize (11 LTS). Less than three crops were recorded in a Belgian, an Estonian and the Dutch LTS, and seven or more crops in 6 LTS of Belgium, Switzerland, Germany and the Czech Republic. All LTS with a small crop diversity were dominated by rotational grassland. Average farm size was between 20 ha (H-NUB) and 1576 ha (C-VER), average field size between 0.8 ha (B-KAP) and 46 ha (D-QFP). The share of permanent grassland varied between 0% in a Dutch (N-BAL), a German (D-QFP) and an Estonian (E-VMA) LTS and 33% in a Czech LTS (C-SVE).

Intensity indicators varied strongly within and between LTS (Table 3). The nitrogen input on the two major crops was similar to the overall N-input, which ranged between 34 kg N/ha in E-VIH and 361 kg N/ha in N-BAL. There was a rather even and linear distribution between those two extremes. The standard deviation of the N-input of the two major crops was below 100 kg N/ha with one exception in Estonia (E-VII). There, one farm indicated nitrogen inputs of up to 650 kg/ha as a result of slurry from a pig fattening enterprise. The mean N-input on permanent grassland ranged between 6 kg N/ha in three of the four Estonian LTS, which corresponds to the atmospheric deposition, and 404 kg N/ha in N-SCH. The standard deviation increased together with the input from 0 to 130 kg N/ha. A comparison with regional statistics (Duthion, 1999; Casagrande and

Table 2
Location and general characteristics of landscape test sites (LTS)

Country	LTS		Longitude	Latitude	No. of growing days	Main type of farm	Two major crops	No. of interviewed farms	Area covered by interviews [ha]	Crop diversity [no. of crops]	Share of permanent grassland [%]	Average farm size [ha]	Average field size [ha]
Netherlands	N-BAL	Balkbrug	6°20′19″	52°34′09″	287	Cattle	RG, MA	10	324	2.3	0.0	32	2.3
	N-BEN	Bentelo	6°40′18″	52°13′28″	277	Cattle	RG, MA	11	310	2.4	4.1	28	1.5
	N-SCH	Scherpenzeel	5°29′48″	52°06′20″	287	Cattle	RG, C	8	240	2.8	6.7	30	1.9
	N-WEE	Weerselo	6°49′08″	52°22′00″	274	Cattle	RG, MA	10	255	2.7	4.3	25	1.6
Belgium	B-BRE	Bree	5°38′51″	51°09′56″	291	Mixed	MA, RG	14	576	3.4	8.3	41	1.3
	B-HOE	Hoegaarden	4°48′37″	50°47′09″	276	Mixed	C, SB	10	752	7.0	7.3	75	0.9
	B-KAP	Meetjesland	3°38′58″	51°14′08″	276	Mixed	MA, RG	13	431	4.4	10.7	33	0.8
	B-VOE	Voeren	5°48′31″	50°41′39″	291	Mixed	RG, MA	11	499	1.2	25.3	45	1.5
France	F-AL	Saint Alban	−2°31′35″	48°31′38″	273	Pig	C, MA	8	446	5.0	6.3	55	1.4
	F-FOD	Pleine-Fougères S	−1°36′59″	48°28′13″	268	Mixed	MA, RG	9	401	5.7	16.7	44	0.8
	F-FOO	Pleine-Fougères N	−1°35′08″	48°32′26″	268	Mixed	MA, C	15	872	5.4	9.4	58	1.3
Switzerland	H-KLG	Klettgau	8°28′39″	47°41′34″	270	Mixed	C, SB	10	301	7.0	16.2	30	1.0
	H-NUB	Nussbaumerseen	8°48′30″	47°35′58″	288	Mixed	RG, MA	10	201	5.5	16.1	20	0.9
	H-REE	Reuss	8°23′00″	47°16′15″	284	Mixed	MA, RG	10	263	5.0	18.0	26	1.1
Germany	D-FRI	Friedeburg	11°42′35″	51°37′04″	254	Arable	C	3	815	7.4	7.4	271	4.2
	D-MFL	Mansfelder Land	11°26′04″	51°37′58″	251	Mixed	C, RG	4	658	7.7	6.2	164	4.2
	D-QFP	Querfurter Platte	11°43′23″	51°22′39″	254	Arable	C	2	660	7.5	0.0	330	46.0
	D-WAN	Wanzleben	11°27′18″	52°04′49″	272	Arable	C, RS	4	430	5.4	8.4	107	8.2
Estonia	E-ARE	Are	24°34′49″	58°29′31″	242	Cattle	RG, RS	10	1185	1.8	2.3	118	5.0
	E-VIH	Vihtra	25°00′46″	58°34′06″	242	Mixed	RG, C	10	1759	3.3	0.8	175	3.7
	E-VII	Viiratsi	25°38′26″	58°20′04″	239	Mixed	RG, C	10	1180	4.5	1.6	118	4.2
	E-VMA	Väike-Maarja	26°16′49″	58°09′24″	235	Cattle	C	11	3939	5.3	0.0	358	5.7
Czech Republic	C-BRO	Broumovsko	16°21′23″	50°32′04″	241	Mixed	C	3	301	3.8	8.3	100	3.9
	C-SVE	Svitnovsko	15°56′48″	49°36′41″	255	Mixed	RG, C	3	1632	7.0	33.3	543	2.8
	C-VER	Veneøicko	14°16′36″	50°41′13″	241	Mixed	C	2	3153	3.4	28.9	1576	5.0

UAA: utilised agricultural area; RG: rotational grassland; MA: maize; C: cereal; SB: sugar beet; RS: rape seed.

Table 3
Intensity indicators for landscape test sites (LTS)

Country	LTS	Nitrogen input [kg N/ha]				Total UAA [kg N/ha]	S.D. [kg N/ha]	Livestock density [LU/ha]	S.D. [LU/ha]	Pesticide input [number of applications]								Total pesticide [number of applications]	S.D. [number of applications]	Index
		Arable crops	S.D.	Permanent grassland	S.D.					Herbicide	S.D.	Insecticide	S.D.	Fungicide	S.D.	Retardants	S.D.			
Netherlands	N-BAL	361	73	0	0	361	73	3.0	1.1	0.3	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.3	0.2	56
	N-BEN	311	103	35	0	299	112	4.7	3.2	0.6	0.3	0.0	0.0	0.1	0.2	0.0	0.0	0.7	0.4	64
	N-SCH	325	96	404	101	331	97	4.3	6.4	0.6	0.6	0.0	0.0	0.2	0.4	0.0	0.0	0.8	1.0	65
	N-WEE	287	59	50	18	277	63	3.1	1.1	0.4	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.4	0.3	49
Belgium	B-BRE	266	33	139	59	255	49	3.1	1.3	1.1	0.4	0.1	0.2	0.5	0.9	0.0	0.0	1.6	1.4	54
	B-HOE	235	58	192	130	232	51	0.6	0.6	1.5	0.7	0.3	0.3	3.3	2.9	0.6	0.0	5.8	2.3	58
	B-KAP	181	49	97	38	172	52	3.6	2.1	1.0	0.1	0.3	0.4	2.8	3.0	0.0	0.0	4.1	3.3	63
	B-VOE	293	84	290	90	293	83	3.2	1.2	0.3	0.4	0.2	0.3	0.4	1.2	0.0	0.0	0.8	1.8	54
France	F-AL	177	25	119	70	173	23	2.7	2.2	1.0	0.4	0.1	0.2	0.9	0.4	0.2	0.2	2.2	0.8	46
	F-FOD	219	25	101	52	199	24	1.1	0.2	1.0	0.0	0.6	0.4	0.2	0.2	0.2	0.1	2.0	0.3	36
	F-FOO	253	52	175	62	245	46	1.0	1.4	1.3	0.5	0.5	0.4	0.6	0.2	0.3	0.2	2.7	0.8	44
Switzerland	H-KLG	155	45	64	48	140	32	0.5	0.6	0.9	0.3	0.1	0.1	0.2	0.2	0.0	0.0	1.1	0.5	21
	H-NUB	209	72	80	77	188	60	1.1	0.7	0.9	0.3	0.4	1.3	0.3	0.6	0.2	0.3	1.8	1.4	34
	H-REE	165	62	78	77	148	55	1.9	0.4	1.0	0.4	0.0	0.0	0.2	0.2	0.2	0.3	1.4	0.8	33
Germany	D-FRI	185	2	27	0	183	5	0.2	0.7	1.0	0.1	0.2	0.4	0.6	0.2	1.0	0.1	2.8	0.7	33
	D-MFL	136	74	95	30	134	69	0.4	0.2	0.6	0.5	0.4	0.4	0.8	0.7	0.6	0.6	2.5	2.1	27
	D-QFP	238	12	0	0	238	12	0.0	0.0	1.0	0.0	1.0	0.1	1.0	0.1	0.3	0.6	3.4	0.8	40
	D-WAN	222	23	24	0	205	59	0.1	0.4	1.2	0.3	0.6	0.3	1.4	0.2	1.1	0.6	4.4	1.0	43
Estonia	E-ARE	39	63	6	0	38	63	1.6	3.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.2	12
	E-VIH	35	23	6	0	34	22	0.2	0.2	0.6	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.5	5
	E-VII	324	229	10	11	319	230	0.3	0.4	1.0	0.3	0.1	0.2	0.0	0.1	0.0	0.0	1.1	0.4	38
	E-VMA	168	48	6	0	168	48	0.9	1.0	0.8	0.3	0.1	0.3	0.0	0.2	0.0	0.0	0.9	0.6	25
Czech Republic	C-BRO	75	12	16	0	70	13	0.0	0.0	1.1	0.1	0.0	0.0	0.6	0.1	0.0	0.0	1.6	0.2	13
	C-SVE	169	25	47	4	128	14	0.6	0.1	0.5	0.4	0.1	0.3	0.3	0.1	0.0	0.0	0.9	0.5	19
	C-VER	39	15	38	15	39	15	0.3	0.2	0.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.6	0.0	6

UAA: utilised agricultural area; LU: livestock units; S.D.: standard deviation.

Table 4
Correlation coefficients (Pearson correlation) between intensity sub-indicators

	N/ha arable crops	N/ha permanent grassland	Livestock density	Herbicide	Insecticide	Fungicide	Retardant
N/ha arable crops	1.00	0.38	**0.53**	−0.00	0.14	0.03	0.00
N/ha permanent grassland		1.00	**0.48**	0.04	−0.01	0.21	−0.06
Livestock density			1.00	−0.38	−0.36	−0.04	**−0.42**
Herbicide				1.00	**0.41**	**0.54**	**0.44**
Insecticide					1.00	0.39	**0.51**
Fungicide						1.00	**0.43**
Retardant							1.00

Significant values ($p \leq 0.05$) are in bold.

Chapelle, 2001; Centre for Research on Agricultural Economics, 2002; VLM, 2002; Luesink and Wisman, 2004) shows a similar N-input level between results of the interviews and the statistics only in Belgium; in France and in the Netherlands, the nitrogen input in the LTS was higher than the nitrogen input according to the statistics (317 kg N/ha versus 175 kg N/ha in the Netherlands, 206 kg N/ha versus 85 kg N/ha in France). These differences are due to the fact that the government statistics relate to specific crops, whereas we investigated the two major crops in each LTS. They also illustrate that for investigations at a local scale, regional statistics are not necessarily appropriate because they average the values over a larger area, whereas in a specific location (LTS), the situation may be quite different.

The average livestock density per LTS varied between 0 and 5.2 livestock units (LU)/ha. In individual, specialised farms in Belgium, the Netherlands and in Estonia, livestock densities of 10 LU/ha and more were recorded. The highest mean values were observed in the Netherlands and in Belgium. Only one of these eight LTS had less than 3 LU/ha, while all other LTS – with one exception in France – had less than 2 LU/ha. The standard deviation ranged from 0 to 6.4 LU/ha. In Belgium and in France, the LU density in the LTS was comparable with regional statistics (Agreste, 2003; Vanorlé and Marvellie, 2003), whereas in the Netherlands, the density of livestock was considerably higher than the national averages (3.8 LU/ha versus 2.3 LU/ha; LEI, 2004). The higher livestock density in the Dutch LTS partly explains the higher N-inputs recorded.

Table 5
Eigenvalues of the seven intensity sub-indicators on the factors 1 and 2 of the factor analysis, explained variance

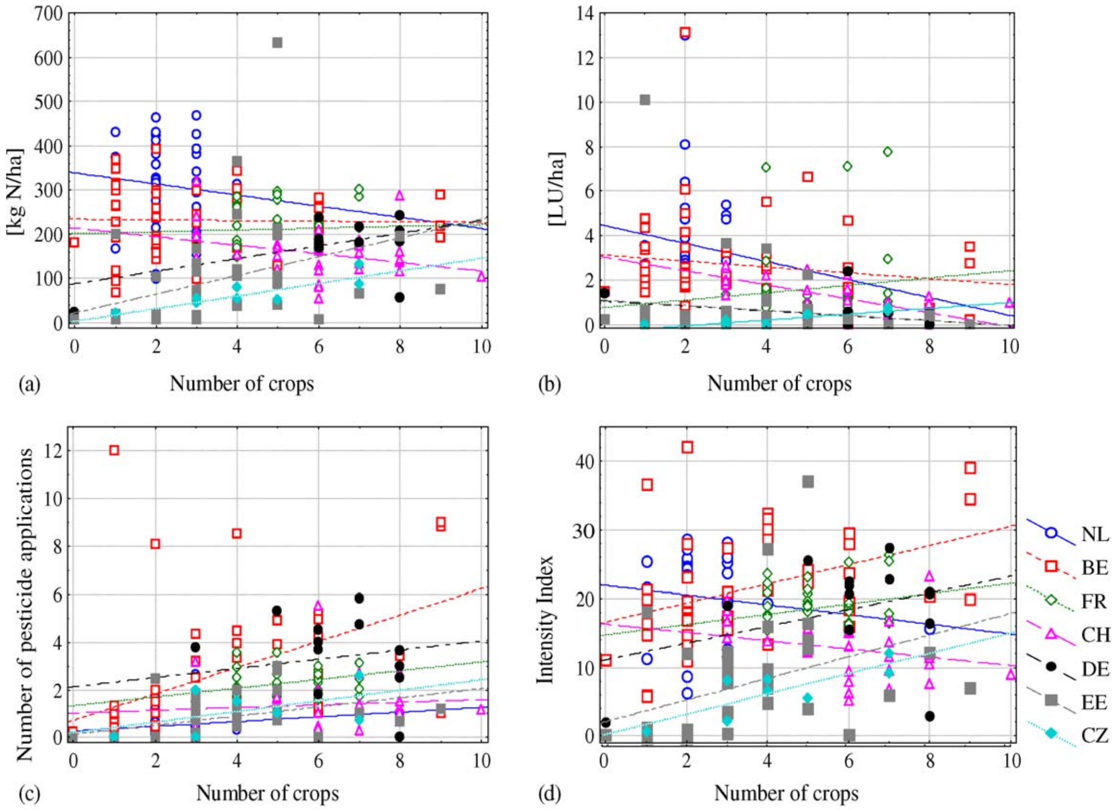
Indicator	Factor 1	Factor 2
N/ha arable crops	0.19	−0.76
N/ha permanent grassland	0.18	−0.77
Livestock density	0.67	−0.62
Herbicide	−0.76	−0.21
Insecticide	−0.73	−0.22
Fungicide	−0.62	−0.46
Retardant	−0.78	−0.11
Explained variance	2.62	1.88
Proportional total	0.37	0.27

Amongst the pesticides, only herbicides were used in all LTS. In more than half of the LTS, no retardants were in use by the interviewed farmers. The highest rates of applications (up to 3.3 in B-HOE) were reported for the fungicides. These were mainly applied to root crops (potatoes and beets) with seven or more fungicide treatments. This made B-HOE the LTS with the highest average number of total pesticide applications. Regional statistics on pesticide applications are only available for France. An average of five pesticide applications per year on wheat

Table 6
Median and *H*-values of the Kruskal–Wallis ANOVA indicating whether the indicator values were at significantly different levels for the landscape test sites of the seven countries investigated and for the comparison between test sites from eastern (Estonia, Czech Republic and former eastern Germany) and western (Belgium, France, the Netherlands and Switzerland) countries

	Median values							*H*-values (country wise)	Mean values		*H*-values (eastern–western comparison
	NL	BE	FR	CH	DE	EE	CZ		Western countries	Eastern countries	
Degree of freedom								6			1
Nitrogen input [kg N/ha]	316	230	203	151	184	55	54	**101.1*****	216	78	**6.3***
Livestock density [LU/UAA]	3.13	2.35	1.05	1.28	0	0.29	0.10	**88.9*****	2.0	0.2	**13.9*****
Pesticide use [no. of applications]	0.39	1.18	2.28	1.00	3.69	0.70	1.25	**67.1*****	1.0	1.0	0.01
Intensity index	20.5	19.7	18.4	12.4	20.8	6.0	7.4	**58.5*****	18.3	8.0	**11.5*****

NL: the Netherlands; BE: Belgium; FR: France; CH: Switzerland; DE: Germany; EE: Estonia; CZ: Czech Republic; LU: livestock unit; UAA: utilised agricultural area.
* $p < 0.05$.
*** $p < 0.001$.



Correlation coefficients (sign. at p<5%, Bonferroni corrected, are printed in bold)

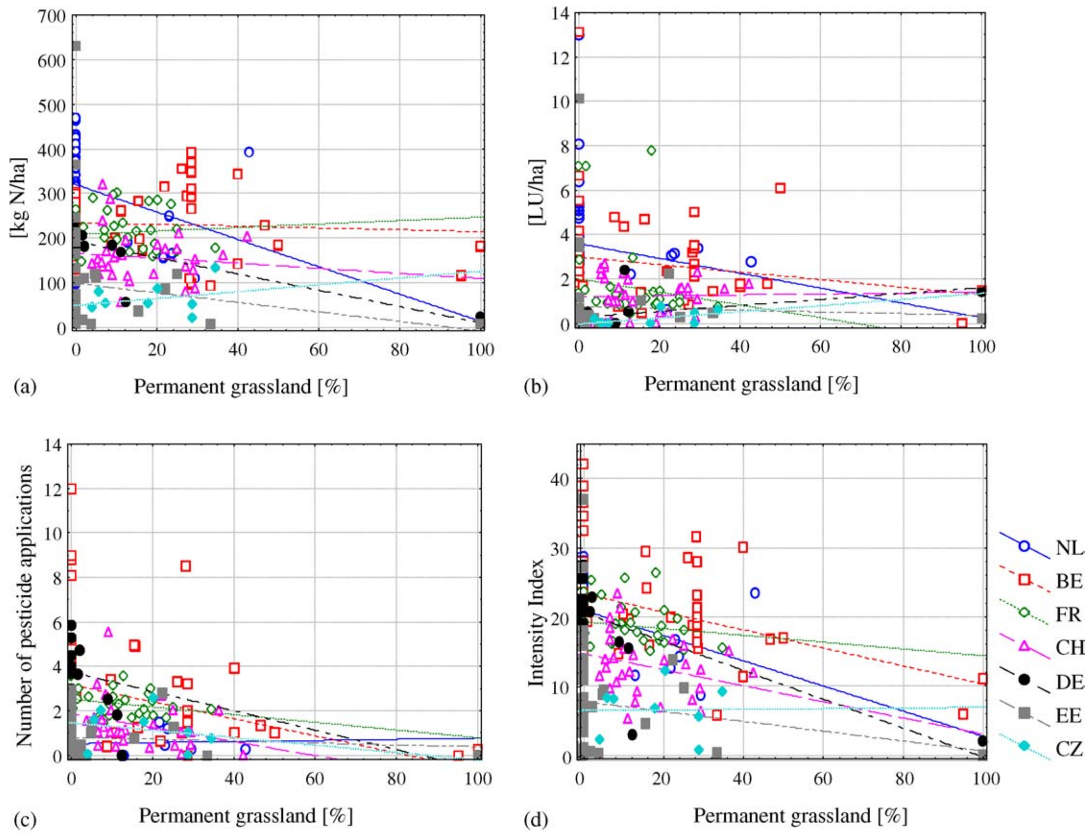
	NL	BE	FR	CH	DE	EE	CZ
a) Nitrogen input	-0.14	-0.03	0.05	-0.32	0.51	0.36	**0.86**
b) Livestock density	-0.20	-0.14	0.10	**-0.68**	-0.35	-0.13	**0.86**
c) Pesticide applications	0.21	**0.47**	0.27	0.09	0.24	**0.45**	0.50
d) Intensity index	-0.14	**0.42**	0.23	-0.25	0.36	0.39	0.82

Fig. 2. Correlations between the number of crops on the farms of all landscape test sites of the seven countries investigated and nitrogen input (a), the density of livestock (b), the number of pesticide applications (c) and the overall intensity index (d). NL: the Netherlands; BE: Belgium; FR: France; CH: Switzerland; DE: Germany; EE: Estonia; CZ: Czech Republic. LU: livestock unit.

is indicated (Rabaud, 2003) which is about twice as much as the average number of treatments recorded in the French LTS (Table 3). However, our results relate to the entire arable land including rotational grassland which is not treated with pesticides.

The last column in Table 3 shows the values of the overall intensity index. It ranged from 5 in an Estonian LTS up to 65 in a Dutch LTS, while values between 0 and 100 were possible. The highest values were found in Belgium and the Netherlands, ranging between 49 and 65. In the middle of the scale, the Swiss, the French and the German investigation areas had values ranging between 21 and 46. The lowest intensity values were found in the Czech and Estonian sites ranging between 6 and 38.

A correlation and a factor analysis were conducted for the intensity sub-indicators to check whether they were reasonably independent, whether some could be discarded and if one indicator was of overriding statistical power to explain the overall intensity of the investigation sites. The analyses yielded some significant, mainly positive correlations between the pesticide indicators, although they were not very high (0.54 at most; Table 4). Livestock density was positively correlated with the N-input factors, but negatively with the pesticide indicators. The factor analysis showed that, although pesticide indicators explained variability between the LTS well (they determined the first axis which accounted for 37% of total variability), nitrogen related indicators were also highly relevant (they determined the second axis which explained 27% of variability) (Table 5). The density of livestock units obviously was a third component of intensity with relatively high Eigenvalues on both axes. None of the indicators, therefore, could substitute the others but it appears that we measured three reasonably independent components of intensity.



Correlation coefficients (sign. at p<5%, Bonferroni corrected, are printed in bold)

	NL	BE	FR	CH	DE	EE	CZ
Nitrogen input	-0.31	-0.06	0.08	-0.11	**-0.77**	-0.15	0.26
LU density	-0.15	-0.18	-0.14	0.02	0.50	-0.04	0.52
Pesticide applications	0.05	-0.31	-0.21	-0.30	-0.65	-0.08	-0.21
Intensity index	-0.33	-0.37	-0.12	-0.28	**-0.73**	-0.15	0.02

Fig. 3. Correlations between the share of permanent grassland in the farms of the landscape test sites of the seven countries investigated and nitrogen input (a), the density of livestock (b), the number of pesticide applications (c) and the overall intensity index (d). NL: the Netherlands; BE: Belgium; FR: France; CH: Switzerland; DE: Germany; EE: Estonia; CZ: Czech Republic; LU: livestock unit.

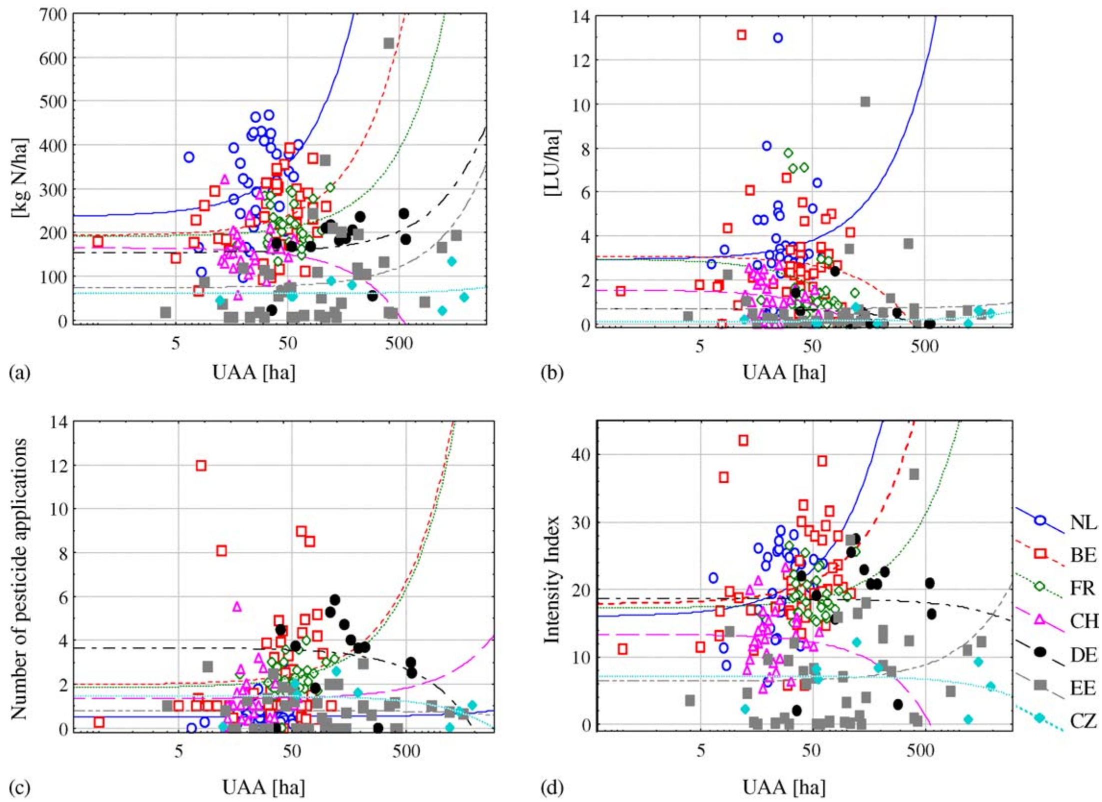
With a Kruskal–Wallis ANOVA, we tested whether the intensity levels differed significantly between countries. For all indicators, the differences between countries were statistically significant and the difference between the two groups of countries (former western and eastern bloc states) was significant except for the number of pesticide treatments (Table 6). This justifies the subsequent analysis of the data per country (Hypotheses 1–3) and per group of countries (Hypothesis 4).

3.2. *Hypothesis 1: A low crop diversity is related to high intensity of agricultural management*

The relation between nitrogen input and crop diversity showed negative trends in Switzerland, Belgium and in the Netherlands. A positive correlation (significant) was found in the Czech Republic and positive trends (not statistically significant) in the remaining three countries (Fig. 2a). Thus, there was no clear relation between the level of nitrogen fertilisation and the number of crops on the farm except for the Czech Republic.

The density of livestock units was negatively correlated with the number of crops on the farm in most countries. Livestock farmers tended to have shorter crop rotations than specialised arable farmers, who tended to grow a wider range of crops (Fig. 2b).

A throughout positive trend (with significant correlation in Belgium and Estonia) was found between the number of crops and the number of pesticide applications (Fig. 2c). This was unexpected because it is generally accepted that an appropriate and diverse crop rotation reduces certain diseases or weeds (e.g. Ledingham, 1961; Karlen et al., 1994; Struik and Bonciarelli, 1997; Riedell et al., 1998; Krupinsky et al., 2002; Cook, 2003; Beckler et al., 2004). However, farmers who cultivated a smaller



Correlation coefficients (none of them was statistically significant at p<5%)

	NL	BE	FR	CH	DE	EE	CZ
Nitrogen input	0.30	0.30	0.18	-0.07	0.27	0.26	0.11
LU density	0.10	-0.10	-0.27	-0.19	-0.38	0.02	0.37
Pesticide applications	0.00	0.09	0.25	0.01	-0.18	-0.03	-0.43
Intensity index	0.32	0.22	0.16	-0.07	-0.03	0.20	-0.22

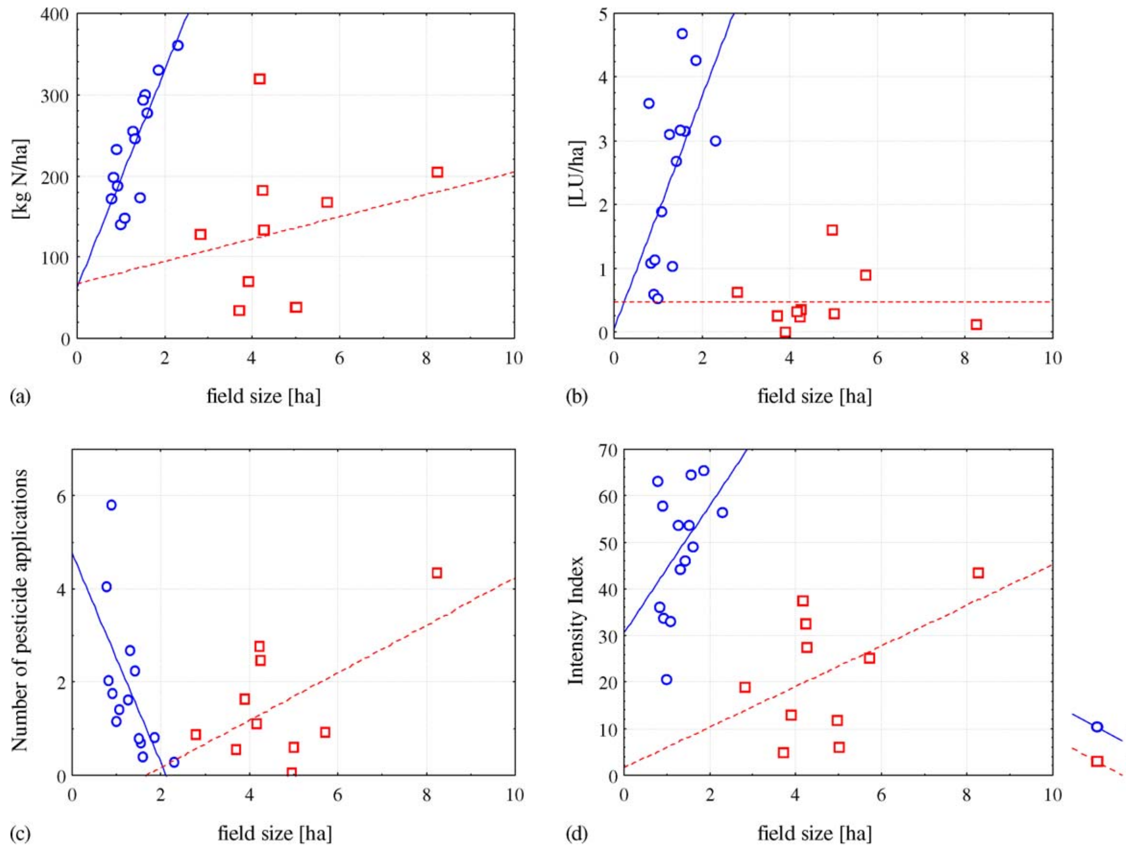
Fig. 4. Correlations between the size of the farms of the landscape test sites of the seven countries investigated (note the logarithmic scale of the *x*-axis) and nitrogen input (a), the density of livestock (b), the number of pesticide applications (c) and the overall intensity index (d). NL: the Netherlands; BE: Belgium; FR: France; CH: Switzerland; DE: Germany; EE: Estonia; CZ: Czech Republic; UAA: utilised agricultural area; LU: livestock unit.

variety of crops tended to concentrate on crop types which are less susceptible to disease and less demanding in terms of plant protection, such as rotational grassland or cereals. On farms with a bigger variety of crops, additional crops were grown that are more frequently treated with pesticides, such as potatoes, which often received seven or more pesticide applications.

Consequently, in most countries, the overall intensity index increased with increasing diversity of farm crops (significant correlation in Belgium) (Fig. 2d) and the hypothesis, that a low number of crops indicates higher intensity, could not be confirmed.

3.3. Hypothesis 2: A high share of permanent grassland is related to low intensity

The overall nitrogen input was negatively correlated to the share of permanent grassland in five of the seven countries investigated (Fig. 3a). For the 13 farmers interviewed in the 4 German LTS, this effect was statistically significant. They had not more than 15% of permanent grassland (with one exception), but it was mostly extensively managed. The nitrogen fertilisation of their arable crops, on the other hand, was relatively high (Table 3). The correlation between the share of permanent grassland and livestock density was negative in four and positive in three countries but none of them was statistically significant (Fig. 3b). There was no significant correlation either with the number of pesticide applications. However, in all countries (except for the Netherlands), there was a trend for farmers, who had dedicated a higher share of their UAA to permanent grassland, to have less pesticide applications on their arable land (Fig. 3c). The overall intensity index generally decreased with an increasing percentage of permanent grassland (Fig. 3d), except in the Czech Republic. The correlation was significant only for Germany.



Correlation coefficients (sign. at p<5%, Bonferroni corrected, are printed in bold)

	W	E
Nitrogen input	**0.84**	0.22
LU density	0.58	-0.00
Pesticide applications	**-0.64**	0.58
Intensity index	0.44	0.48

Fig. 5. Correlations between the average field size in the landscape test sites of the western European countries (W: The Netherlands, Belgium, France and Switzerland) and the former eastern bloc states (E: Eastern Germany, Estonia and Czech Republic) and nitrogen input (a), the density of livestock (b), the number of pesticide applications (c) and the overall intensity index (d). LU: livestock unit.

In general, the hypothesis that an increasing share of permanent grassland indicates a decreasing land-use intensity can be maintained. However, only a few of the correlations were statistically significant and it should be noted that the amount of fertiliser for permanent grassland can be very high (e.g. mean value in N-SCH: 404 kg N/ha).

3.4. Hypothesis 3: Large farms are managed more intensively

The N-input was higher on large farms in all countries except Switzerland, but there were no significant correlations (Fig. 4a). Livestock density was higher on larger Dutch, Estonian and Czech farms; in all other countries, the contrary was observed but again, there were no significant correlations (Fig. 4b). There was also no clear relation and no significant correlation between the number of pesticide applications and farm size (Fig. 4c). More detailed investigations were made for specific farm types (arable, mixed and cattle), but none of them showed a significant correlation between farm size and pesticide applications.

For none of the countries, the correlation between overall intensity index and farm size (positive: Netherlands, Belgium, France and Estonia; negative: Switzerland, Germany and Czech Republic) was found to be statistically significant (Fig. 4d). The hypothesis, that large farms are managed more intensively, could therefore not be confirmed.

3.5. Hypothesis 4: Large fields are managed more intensively

The average field sizes were in two different orders of magnitude. In the western European LTS, field size was not more than

2.3 ha (N-BAL), whereas in the eastern European LTS it ranged between 2.8 and 46 ha (C-SVE and D-QFP, respectively). For this reason, the hypothesis was investigated separately for these two groupings of countries. Positive correlations were found between field size and nitrogen input (Fig. 5a). The correlations were statistically significant for the group of the western European countries, but only slight (and not significant) for the former eastern bloc states. The analysis of the relation between field size and LU density as well as the number of pesticide applications yielded contrasting results. LU density increased with field size in the western European countries, whereas in the eastern European countries there was no relation (Fig. 5b). In western Europe, the number of pesticide applications decreased significantly with increasing field size, whereas the contrary was observed in eastern Europe (Fig. 5c). The resulting overall intensity index showed a slight – but not significant – positive correlation with increasing field size for both groups of countries (Fig. 5d).

The contrasting correlations between field size and pesticide applications in eastern and western Europe can be explained by a negative correlation between field size and the number of crops in the rotation (data not shown). Within the group of the western European LTS, the crop rotation was more diverse and contained more crops which are frequently treated with pesticides on the generally smaller fields. In the LTS where rotational grassland had a high share of the crop rotation (including, e.g. the Dutch LTS), the average field size was larger. This resulted in a negative correlation between field size and the number of pesticide applications for the western European LTS. Although we could not statistically confirm the hypothesis that field size and agricultural intensity are positively correlated, we observed a trend for both, eastern and western European countries.

4. Conclusions

Our overall methodological conclusion is that in the context of landscape related investigations, it is helpful to base the assessment of the intensity of agricultural management on a definition of intensity which can be expressed through physical inputs that directly act on the environmental variables of interest. With a relatively simple questionnaire, the necessary information could be obtained from farmers. This information is more specific for the region under investigation than regional statistical data which – moreover – in cross-country comparisons are either not available at all or are not comparable. When preparing the farmer interviews, the importance of clearly defining all terms and questions needs to be stressed. Particular attention must be paid to grassland which, due to the flexible management with mixed grazing and mowing regimes over a wide degree of intensity, can easily lead to confusion.

We measured three reasonably independent components of intensity (nitrogen input, livestock density and pesticide input), none of which were of overriding statistical power. Hence, all three components need to be considered. Whereas this investigation was conducted in the context of landscape biodiversity research, the same approach could possibly be extended to other environmental compartments, e.g. water quality, as the major agricultural inputs are covered by the individual indicators. The indicators were aggregated then into an index in order to reflect overall intensity. Aggregated indices have the merit of simplifying complex situations. This is, however, at the expense of transparency and interpretability. Whether indicators or indices should be used depends on the purpose of a study. In our case, we found that the interpretation of the overall index was only possible while referring to the individual indicators of nitrogen input, livestock density and pesticide application.

The first hypothesis, that a low crop diversity is linked to higher intensity, could not be confirmed and in most countries, the contrary was observed. This was due to the fact that with an increased number of crops, the share of those which are demanding in terms of plant protection and fertilisation increased. This does not imply that short crop rotations should be recommended because they would lead to an extensification. Countless experiments and observations have demonstrated the necessity of crop rotations to prevent diseases and weeds (e.g. Ledingham, 1961; Karlen et al., 1994; Struik and Bonciarelli, 1997; Riedell et al., 1998; Krupinsky et al., 2002; Cook, 2003; Beckler et al., 2004), conserve soil fertility (Riedell et al., 1998; Watson et al., 2002), improve nutrient and water use efficiency (Karlen et al., 1994; Varvel, 1994) and increase yield sustainably (Struik and Bonciarelli, 1997; Riedell et al., 1998). It does imply, however, that it is rather the type than the mere number of crops, which indicate the degree of intensity of agricultural management and that the number of crops in the rotation cannot be used as a surrogate value for land-use intensity. Subsequent analysis will focus on the relationship between the number of crops and biological diversity. We expect this correlation to be positive because additional crops increase habitat diversity and thus the environmental niches.

The second hypothesis stipulating that an increase of permanent grassland would indicate a reduction of the intensity of agricultural land-use was generally confirmed. On permanent grassland, there is no pesticide application, overall intensity is thus reduced when the share of permanent grassland increases. The correlation between the share of grassland and the density of livestock was rather weak. This can be an indication for the de-coupling of livestock production and grassland area. In many countries, ruminants are fed the longer the more with feed from arable crops (maize and cereals) rather than being put out to graze. There are, however, permanent grasslands which are very intensively managed and receive high nitrogen inputs.

The third hypothesis – large farms are managed more intensively – could not be confirmed. There was no clear trend, neither for individual countries, nor for specific indicators, nor for particular farm types. We conclude that farm size and farming intensity are not related (see also Roschewitz et al., 2005). One can argue that larger farms are more professionally managed and more profit orientated but apparently this does not necessarily lead to higher levels of intensity. Small farms, on the other hand, which are at the lower limit of economic viability, may be forced into higher levels of intensity in order to achieve the minimum income required to remain viable. These two trends may compensate.

The fourth hypothesis, that large fields are managed more intensively, appears to hold true for the N-input, but could not be verified for the livestock density and pesticide applications. There were more pesticide applications on smaller fields because they generally had more diverse crop rotations and a higher share of special crops, which are more dependent on plant protection. However, it has been shown that diseases and pests spread less rapidly in small scale mosaic landscapes than in large monocultures (Basedow, 1990; Marino and Landis, 1996; Landis et al., 2000), because predators and parasitoids take advantage of uncultivated refuges in the vicinity of fields (Elliot et al., 1998; Thies and Tscharntke, 1999; Sunderland and Samu, 2000; Langellotto and Denno, 2004). We conclude that field size cannot be used as a surrogate value for farming intensity regardless of the crop type.

The contrasting trends which some individual indicators showed, namely for Hypotheses 1 and 4, restrict the suitability of an overall index of intensity. As a consequence, an analysis of the relationship between land-use intensity and biodiversity or water quality characteristics should be based on individual indicators rather than on an overall index. In fact, the intensity indicators contributed to explain the variability of the observed biodiversity in the LTS (Aviron et al., 2005; Dormann et al., submitted for publication; Schweiger et al., in press). Working with actual indicators, which have a physical unit (e.g. kg N/ha), has the merit of being more readily interpretable and transparent, whereas the overall index is likely to blur causal relationships between components of intensity and environmental variables.

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