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**Cropping system intensification grading using an agro-environmental indicator set in northern Italy**

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## UNIVERSITÀ DEGLI STUDI DI TORINO

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1 CROPPING SYSTEM INTENSIFICATION GRADING USING AN AGRO-  
2 ENVIRONMENTAL INDICATOR SET IN NORTHERN ITALY

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12 Title: CROPPING SYSTEM INTENSIFICATION GRADING USING AN AGRO-  
13 ENVIRONMENTAL INDICATOR SET IN NORTHERN ITALY

14

15 **Abstract**

16 The term agro-environmental sustainability in agriculture usually refers to farming intensity.  
17 Lower intensity farming can be managed by reducing chemical and energy inputs. Beyond  
18 ethical issues and having in mind only agronomic aspects, cropping systems are defined by  
19 regulations that classify them according to their different input levels as conventional (most  
20 intensive), integrated (intermediate intensity), and organic (least intensive).

21 Among organic cropping systems, it is expected that the most intense cropping level would be  
22 arable farms where there is a greater need to import input factors, and the least intense level  
23 would be livestock farms. This research aims to systematically grade conventional, integrated,  
24 and organic cropping systems using a set of 22 indicators of input and environmental  
25 pressure. The grading results will then be compared to regulation-defined intensities.

26 Eight cropping systems belonging to four intensification levels were analysed by an indicator  
27 set classified as driving force or pressure indicators per the DPSIR schema. Driving forces  
28 represented farmer management decisions; pressures represented stressors to the environment  
29 resulting from agricultural activities not directly modifiable by the farmer. The 22 indicators  
30 analyse five aspects of cropping system: land use, fertiliser use, pesticide use, energy use and  
31 gaseous emissions.

32 Study results showed that most indicators were able to accurately grade the cropping system  
33 intensities. Specific driving forces and pressures indicators that failed to grade the cropping  
34 systems as expected related to several explainable factors. For driving force indicators,  
35 conventional systems demonstrated the highest impact on the environment and arable organic  
36 cropping systems the lowest. For pressure indicators, conventional cropping system presented

37 the highest impact, followed by integrated cropping systems. In this case the arable organic  
38 cropping system presented a higher impact than did the livestock organic system. This level  
39 of discrimination showed that pressure indicators performed better at grading system  
40 intensification than did driving force indicators.

41 As a consequence, the analysis showed that higher input levels do not always result in higher  
42 pressures on the environment. Therefore, the environment would be better served by  
43 regulations that set thresholds for pressures rather than system inputs. The results also  
44 underlined that practices such as manure use and meadow presence improve the  
45 environmental performances of cropping systems.

46

47

48 Key words: Agro-environmental sustainability assessment, environmental impact, organic  
49 farming, integrated farming, conventional farming.

## 50 1 Introduction

51 Over the past 60 years, European agriculture has undergone a period of rapid intensification  
52 achieved through an increased application of chemical fertilisers and pesticides, combined  
53 with implementation of best management practices, mechanisation, irrigation, and with the  
54 use of improved seed varieties (Tilman et al., 2002). Today, the term “agro-environmental  
55 sustainability” has come to imply high dry matter (DM) yields and society’s expectation for  
56 ecological service while complying with European environmental programs (Cross-  
57 compliance 73/2009/EC (EC, 2009a), Water Framework Directive 60/2000/EC (EC, 2000),  
58 Sustainable use of pesticides Directive 128/2009/EC (EC, 2009b), Birds Directive  
59 147/2009/EC (EC, 2009c), and Habitats Directive 43/1992/EEC (Council of the European  
60 Communities, 1992)). These changes have led public and scientific communities to turn their  
61 attention to alternative farming systems including, among others, integrated farming,  
62 precision farming, conservation agriculture, and organic farming.

63 All of the above distinguish themselves from intensive conventional systems in their  
64 improved resource use efficiencies, rather than on external inputs to maintain productivity and  
65 profitability (Liebman et al., 2008). Low external-input and organic cropping systems could  
66 provide a good compromise between intensity (level of input used per unit of surface) and  
67 efficiency (quantity of product obtained per level of input used) (Alluvione et al., 2011;  
68 Michos et al., 2012; Pointereau et al., 2012).

69 Cropping system intensity is defined by European, national, and regional level regulations.  
70 This paper considers only the agronomic aspects, contained in the different regulations and do  
71 not consider the different ethical aspects that have led to them. Conventional cropping  
72 systems must satisfy statutory management requirements defined in the cross compliance  
73 system (73/2009/EC (EC, 2009a)), which represent the minimum legal limits. In Italy, the  
74 regional Rural Development Program (RDP) determines regulations for integrated farming

75 systems, whereas organic agriculture is governed by European regulations 834/2007/EC (EC,  
76 2007) and 889/2008/EC (EC, 2008). Among low-input cropping systems, integrated  
77 agriculture has been promoted for its reduced environmental impact and increased sustainable  
78 resource use (Alluvione et al., 2011; Morris and Winter, 1999). Organic farming has also been  
79 advocated as more sustainable than conventional systems over the long-term (Pimentel et al.,  
80 2005), as it uses the fewest inputs and therefore, is the least intense. Banned chemical  
81 products, improved nutrient recycling, and “minimisation of the use of non-renewable  
82 resources and off-farm inputs” are keys to its sustainability (Regulation 834/2007/EC (EC,  
83 2007)).

84 When livestock production systems are paired with organic systems, further efficiency and  
85 sustainability is achieved. Regulation 834/2007/EC has defined livestock production as  
86 “fundamental to organization of agricultural production...” because it can provide organic  
87 nutrients to the cropping system through within-the-farm recycling, and allows for  
88 partitioning between low sustainability/externally- and high sustainability/internally-produced  
89 inputs (Nemecek et al., 2011). From this follows that in organic farms the highest  
90 intensification level should be on arable ones because they require more imported inputs;  
91 conversely, the lowest intensification level should be on livestock organic farms as they  
92 utilise nutrient recycling to meet many of their input needs.

93 Several authors have confirmed the relationship between lower intensification level and lower  
94 environmental pressures (i.e. Flessa et al., 2002; Kramer et al., 2006; Liu et al., 2007).  
95 Environmental pressures, however, have not always corroborated the expectations associated  
96 with the intensification levels described above, with organic cropping systems being less  
97 sustainable than conventional systems (Kirchmann and Bergström, 2001; Eltun et al., 2002;  
98 Basset-Mens and van der Werf, 2005). Finally, van der Werf et al. (2007), comparing many  
99 assessment methods applied to farms producing crops and pigs, found that the rank between

100 organic and conventional farms depends on the assessment method applied and on the aspect  
101 analysed.

102 Field experiments and farm measures are two ways to evaluate directly the agro-  
103 environmental sustainability of different cropping systems, however, these methodologies are  
104 time-consuming when many aspects are analysed. “Indicators are an alternative when it is not  
105 possible to carry out direct measurements” (Bookstaller et al., 1997). They allow not only an  
106 understanding of complex systems (Mitchell and al., 1995), but also compare different  
107 situations, two characteristics that make them highly useful in the analysis of agricultural  
108 managements and their environmental pressures.

109 Different authorities — at both the European and worldwide scales — have created lists of  
110 indicators. Among them there are: EU Agro-Environmental indicators AEI (COM (2006) 508  
111 (EC, 2006)), OECD agro-environmental indicators (OECD 1999), and FAO agro-  
112 environmental indicators (FAO, 2012). At the European level indicators are also used to  
113 evaluate environmental policy effects. Some indicators are suitable to analyse different levels  
114 of complexities, such as Input Output Account (IOA) (Halberg et al., 2005), the Life Cycle  
115 Assessment (LCA) (ISO 2006), and the Ecological Footprint (EF) (Rees, 2000). The IOA has  
116 been applied to different sustainability aspects, but in particular, to nutrient balances  
117 (Bassanino et al., 2007; Oenema et al., 2003; Schröder and Neetson, 2008) and energy balances  
118 (Alluvione et al., 2011; Meul et al., 2007). In the case of the LCA and EF, they analyse the  
119 sustainability of the entire production system via pressure category assessment. Analysis of  
120 specific pressures related to different agricultural managements is most useful when  
121 performed by single indicators or indicator sets.

122 This work analyses different cropping systems at various intensification levels (conventional,  
123 integrated, and organic) using an agro-environmental indicator set built of different indicators  
124 derived from literature. The investigation aims to grade these cropping systems on both input

125 level and environmental pressures; thereafter, the results will be compared to the expected  
126 grade derived from the intensification levels as defined by regulation.

127

## 128 2 Materials and methods

### 129 2.1 Description of the area

130 The study was carried out in the western Po Valley (Piemonte Region, NW Italy). The climate  
131 is temperate sub-continental, characterised by two main rain periods in spring and autumn,  
132 with an annual mean precipitation of 850 mm and an annual mean temperature of 11.8°C. The  
133 soil types are Inceptisols, Entisols and Alfisols (Bassanino et al., 2007), mainly characterized  
134 by silt-loam and silt texture.

135 According to the regional administrative database (Regione Piemonte, 2010), arable and  
136 livestock farms cover most of the Utilized Agricultural Area (UAA). Conventional arable  
137 farms are in the majority (94.5%) while integrated and organic farms represent just 4.9% and  
138 0.6%, respectively. The main arable farm crops were maize (*Zea mays* L.), winter cereals  
139 (*Triticum aestivum* L., *Hordeum vulgare* L.), soybean (*Glycine max* (L.) Merr.), and meadows  
140 (Sacco et al., 2003). Livestock farms bred principally bovine and swine. Bovine livestock  
141 farms fell into one of three breeding types: beef, dairy cows, or suckling cows (Bassanino et  
142 al., 2007), with suckling cows comprising the largest share at 47%, of which 1.2% were  
143 organic farms. Bovine livestock farm main crops included maize (for grain and silage  
144 production), winter cereals, lucerne (*Medicago sativa* L.), Italian ryegrass (*Lolium*  
145 *multiflorum* Lam.), and hay-producing meadows (mixed grasses and legumes).

146

### 147 2.2 Farm types

148 Conventional, integrated, and organic cropping systems of farms were considered in this  
149 study. Organic farms were further divided into arable organic farms and livestock organic

150 farms according to their external input levels, which created four different farm intensification  
151 groups:

- 152 - conventional arable farms (CONV)
- 153 - integrated arable farms (INT)
- 154 - organic arable farms (ORG)
- 155 - organic livestock farms (LIV)

156 Two farms were selected at each intensification level, to represent the variability of farm  
157 managements and input use levels. Organic livestock farms were selected from the suckling  
158 cow breeding type. We further focused our work on cropping systems alone. From  
159 conventional and integrated farms, only those that applied mineral fertiliser were chosen to  
160 represent typical farmer behaviour in the area.

161

#### 162 2.2.1 Farm survey and data collection

163 Farm management and cropping system data included farm characteristics, crop production  
164 and management, farm inputs and outputs, and animal production. They were collected using  
165 a structured questionnaire, progressively completed during an average of two face-to-face  
166 interviews of about two hours each. Subsequently, the information was organized and stored  
167 in a Microsoft Excel© file for later calculation of the agro-environmental indicators.

168 Soil samples were taken from four representative fields at each farm at a depth of 0.3 m.  
169 Official Italian soil analysis methods (MIPAAF, 2000) were used to analyse sample texture,  
170 pH, organic carbon content, total N, Olsen P, and exchangeable K.

171

#### 172 2.2.2 Farm descriptions

173 Table 1 reports a general description of the farms. The average UAA was 48 ha. The two  
174 organic arable farms were the smallest at 19 and 24 ha, while the other farms were more

175 variable. Soil textures were loam or silt-loam; other soil characteristics varied more. Organic  
176 matter content was higher in livestock organic farms, followed by arable organic farms. The  
177 other arable farms were the lowest, except for one conventional farm that had a previous  
178 presence of permanent grassland. Total N content nearly tracked the organic matter trend as  
179 C/N ratio did not show a large variability. Olsen P levels were high in all the farms, and  
180 homogeneous among the groups. Exchangeable K was usually low.

181 Table 2 presents the crops and their yields of each farm. As expected for the area, the major  
182 crops were maize and winter cereals, followed by soybean. In addition to these crops, organic  
183 farms also included various legumes (mostly lucerne) in their crop rotation. Meadows and  
184 other forages were present on organic farms only.

185 The organic livestock farms bred 120 and 89 Livestock Units (LSU) with stocking rates of 3.4  
186 and 1.7 LSU ha<sup>-1</sup>, respectively. Manure was managed by a permanent litter made of barley  
187 straw and maize stalk residue. Manure was spread mainly inside the farms, but farmyard  
188 manure quotas of 22% and 13%, respectively, were still exported to neighbouring farms. The  
189 spread manure limit of 170 kg N ha<sup>-1</sup> was accomplished on both farms.

190

### 191 2.3 Application of agro-environmental indicators

192 The selected farms were analysed using the set of 22 indicators derived from literature and  
193 reported in Figure 1. Those selected, according to the DPSIR schema (Kristensen, 2004; EEA,  
194 2005), can be classified as driving force or pressure indicators. Driving force indicators  
195 represent system inputs related to land use planning, agricultural managements, chemical, and  
196 energy; pressure indicators represent the result of these practices and are usually not directly  
197 modifiable by farmers. Oenema et al. (2011) considers the AEI “soil cover” indicator a  
198 driving force indicator, however, we considered it a pressure indicator to recognize that

199 farmers actively select the number and type of crops to grow based on economic strategies  
200 rather than on simply covering the soil for longer.

201 Figure 1 makes clear how driving forces and pressures relate. Some pressure indicators (soil  
202 cover, fertiliser, and pesticide indicators) relate to just one or few driving force indicators,  
203 while others (gaseous emissions and energy indicators) relate to most. Separating driving  
204 force indicators and pressure indicators allows analysis of the critical points of cropping  
205 systems and makes evident the agricultural managements that cause the pressures.

206 Indicators were selected to evaluate the agro-environmental sustainability of cropping system  
207 managements from five aspects (land use, fertiliser use, pesticide use, energy use and gaseous  
208 emissions). To each aspect corresponded a group of indicators. The different indicators, with  
209 the exception of *Number of practices*, derived from the literature and international  
210 methodologies. Most came from Agro-Environmental indicators (AEI) that have been defined  
211 in Communication COM (2006) 508 of the European Commission (EC, 2006). *Number of*  
212 *Crops, Tillage Practices, and Irrigation* were directly calculated at the cropping system scale,  
213 while all others were calculated at the crop level and related to the cropping system scale  
214 using a weighted average based on the surface of each crop.

215 Pressure indicators were calculated using standardized international methodologies and were  
216 not directly measured. Pressure indicators have the advantage that they are based on  
217 information easily collectable from farm interviews and official databases. The relationship  
218 between indicator results and effective impact on the system is described in the cited  
219 literature.

220 The majority of indicators represented system inputs (driving force indicators) or system  
221 impacts (pressure indicators), and therefore, results were generally considered to have lower  
222 sustainability when their values were high. However, *Number of Crops, Number of Practices,*

223 *Soil Cover, Gross nutrient balances, Net Energy, and Energy Use Efficiency* have different  
224 interpretations, which have been detailed in the specific section.

225 Due to the large pedological and climatic variability that affects crop production, indicators  
226 results were presented only per unit of surface and not per unit of production.

227

### 228 2.3.1 Driving force indicators

#### 229 2.3.1.1 Land use

230 Three indicators comprise the Land use driving forces group: *Number of Crops, Tillage*  
231 *Practices, and Irrigation*, all of which were derived from AEI indicators (Oenema et al.,  
232 2011). *Number of Crops* defines the number of different species cultivated without regard to  
233 final use (grain, silage, green forage, or hay). It indicates the structural biodiversity of a  
234 cropping system. *Number of Crops* indicator show higher sustainability when values are high.  
235 *Tillage Practices* highlights the different practices applied on a farm, and is calculated as the  
236 percentage of the UAA cultivated with conventional practices. *Irrigation* does not consider  
237 the potential irrigable land; rather, it indirectly measures water consumption as the percentage  
238 of the UAA that is effectively irrigated.

239

#### 240 2.3.1.2 Fertiliser use

241 Five indicators belong to the Fertiliser use driving forces group: *Mineral fertilisers, Organic*  
242 *fertilisers, N fertilisers, P fertilisers, and K fertilisers*. All five were derived from the AEI  
243 fertiliser consumption indicator (Oenema et al., 2011), and each was calculated as the total  
244 amount of fertiliser or nutrient applied to a hectare ( $\text{kg ha}^{-1}$ ). The nutrient quantities applied  
245 through farmyard manure were calculated using a mass balance (Amon et al., 2011) that  
246 considered feed and litter nutrient content as inputs and nutrients exiting the system via  
247 pathways other than excreta as outputs.

248

#### 249 2.3.1.3 Pesticides use

250 The two indicators in the Pesticides use driving forces group are *Consumption of Pesticides*  
251 and *Equivalent Treatment*. The former, an AEI indicator (Oenema et al., 2011) is the total  
252 active ingredient quantity applied to a hectare ( $\text{kg ha}^{-1}$ ), while the latter is the number of  
253 average treatments used and is quantified as the ratio between actual applied pesticide  
254 quantity and average quantity suggested by the manufacturer (Dennis et al., 2010).

255

#### 256 2.3.1.4 Energy use

257 The two indicators that belong to the Energy use driving forces group include *Number of*  
258 *Practices* (not reported in the literature) and *Energy Input* (Alluvione et al., 2011), which  
259 corresponds to the AEI indicator Energy Use as defined by Oenema et al. (2011). *Number of*  
260 *Practices* equals the number of tillage, sowing, fertilisation, weeding, ridging, irrigation,  
261 harvesting, silaging, and drying events performed per crop. Each operation counts as a unit  
262 regardless of the time or energy consumed. *Energy Input* (EI) is the sum of direct and indirect  
263 energy inputs. Fertilisers, pesticides, seeds, diesel, and lubricant constitute direct energy  
264 inputs, while indirect energy inputs are those used to produce, package, and transport the  
265 direct inputs and energy embedded in farm machinery. Notably absent from the EI are  
266 environmental and labour inputs (Alluvione et al., 2011).

267 All energy inputs, both direct and indirect, were calculated through mass flow and determined  
268 by multiplying inputs by the equivalent energy shown in Table 3, that represents the energy  
269 embedded in each product. The value for fertiliser energy input was computed by multiplying  
270 various N forms, P, and K quantities by their specific energy equivalent, and then the product-  
271 specific Formulation Packaging Transport coefficient (FPT) was added. Manure has no  
272 energy equivalent because it is a livestock farming by-product. Pesticide energy input was

273 determined by multiplying the quantity of each active ingredient by its specific energy  
274 equivalent (Green, 1987), and then adding the pesticide FPT coefficient. Average herbicide,  
275 fungicide, and insecticide energy values were employed when necessary. Seed energy  
276 equivalents included the energy required for selecting, packaging, and transporting the seeds.  
277 Fuel energy input values were based on farmer reported diesel consumption; total lubricant  
278 energy (direct + indirect) and machine-embedded energy were considered to be proportional  
279 to diesel consumption. Table 4 lists the maximum and minimum values for each practice.

280

### 281 2.3.2 Pressure indicators

#### 282 2.3.2.1 Land use

283 *Soil Cover* was the land use pressure indicator used in the present study. It is from the AEI  
284 indicator set (Oenema et al., 2011), and when combined with *Tillage Practices* (AEI), can be  
285 used to evaluate soil erosion risk (Bockstaller et al., 1997; Vereijken, 1995; Castoldi and  
286 Bechini, 2006). *Soil Cover* (SC) is defined as the number of days (expressed as year  
287 percentage) during which the crop is present. High values (long soil coverage period) equate  
288 to more system sustainability.

289

#### 290 2.3.2.2 Fertiliser use

291 Three indicators belong to the fertiliser use pressure group: *Gross N Balance* (GNB), *Gross P*  
292 *Balance* (GPB), and *Gross K Balance* (GKB). GNB and GPB were calculated according to  
293 AEI indicators (Oenema et al., 2011); GKB was calculated following Bassanino et al. (2011).

294 The gross nutrient balances were calculated as:

$$295 \text{GNB, GPB and GKB} = F_c + F_o + A_d + B_{fx} + S_e - \text{Off}$$

296 where  $F_c$  was the mineral fertiliser nutrient supply,  $F_o$  was the organic fertiliser nutrient  
297 supply,  $A_d$  was the N and P atmospheric depositions,  $B_{fx}$  was the biological nitrogen fixation

298 by legumes,  $Se$  was the seeds nutrient content, and  $Off$  was the crop nutrient off-take. The  
299 values utilised for nutrient content both in crops and seeds are shown in Table 5. The values  
300 used for atmospheric deposition were  $26 \text{ kg N ha}^{-1} \text{ y}^{-1}$  (Bassanino et al., 2011) and  $1.8 \text{ kg P}$   
301  $\text{ha}^{-1} \text{ y}^{-1}$  (study area value, Experimental Centre, University of Turin). The legume fixation  
302 value was calculated as:

$$303 \text{ Bfx} = \text{Off} - (\text{Fc} + \text{Fo} + \text{Ad} + \text{Se})$$

304 on pure legume crops (soybean, lucerne, beans) (Bassanino et al., 2007; Grignani et al.,  
305 2003); in meadows and permanent grassland (composed of grasses and legumes), the N fixed  
306 value considered was  $40 \text{ kg N ha}^{-1}$  (Regione Piemonte, 2009). This assumption derives from  
307 the simplified ideas that these crops tend to use N from fertilisers, before fixing atmospheric  
308 N (Meisinger and Randall, 1991) and that their balance is equal to zero (Bassanino et al.,  
309 2007).

310 Gross nutrient balances were difficult to evaluate for agro-environmental sustainability as  
311 they could result in either positive or negative values. Although the surplus of gross nutrient  
312 balances includes potential soil immobilisation, they also indicate nutrient loss potential due  
313 to gaseous emissions, leaching, and run-off. Therefore, a higher surplus suggests higher losses  
314 and higher environmental impact. On the contrary, negative values or deficits, imply nutrient  
315 use from immobilised soil pools, potentially leading to a depletion of soil nutrients. In  
316 summary, gross nutrient balances were considered “better” when closer to zero and “worse”  
317 when high (absolute value), as it would imply greater losses or soil depletion.

318

### 319 2.3.2.3 Pesticide use

320 The two indicators in the pesticides use pressure group are *Load Index* and *Environmental*  
321 *Impact Quotient*. The *Load Index* (LI) (Bechini and Castoldi, 2009; OECD, 2004) indicates  
322 potential effect on a non-target organism class. It is calculated by dividing the application rate

323 by the LD50 or the LC50 of each active ingredient. The *Environmental Impact Quotient*  
324 (EIQ) value (Kovach et al., 1992) is more complex to calculate as it takes into account active  
325 ingredient properties and analyses the potential impact on three different components:  
326 farmers, consumers, and environment. The present work used the active ingredient properties  
327 defined by the Pesticide Property Database (University of Hertfordshire, 2012) and the Italian  
328 Ministry of Agriculture database (MIPAAF, 2012).

329

#### 330 2.3.2.4 Energy use

331 Two indicators in the energy use pressure group are *Net Energy* and *Energy Use Efficiency*.  
332 *Net Energy* (NE) and *Energy Use Efficiency* (EUE) indicators (Alluvione et al., 2011) allow  
333 evaluation of energy output as well as the relationship between yield and plant production  
334 energy used. The data needed to calculate these indicators are energy input and energy output.  
335 *Net Energy* is the difference between energy output and energy input, while *Energy Use*  
336 *Efficiency* is the ratio between energy output and energy input.

337 Inputs were determined per the *Energy Input* indicator described earlier. Energy outputs were  
338 defined as the gross energy contained in crops and residues removed from the field (Table 3).  
339 The *Net Energy* represents the amount of energy gained per unit of area, while the *Energy Use*  
340 *Efficiency* represents the energy gained per unit of energy input. Therefore, larger values  
341 correspond to lower impact.

342

#### 343 2.3.2.5 Gaseous emissions

344 *Ammonia Emission* and *GHG Emission* are the two indicators in the Gaseous emissions  
345 pressure group. According to AEI (Oenema et al., 2011), the methodologies used for gaseous  
346 emissions are those internationally recognized by law. These methodologies are EMEP/EEA  
347 for ammonia (EEA, 2009) and IPCC for greenhouse gases (GHG) (IPCC, 2006).

348 A Tier 2 approach (EMEP/EEA methodology) was used for mineral and organic fertiliser  
349 calculations of the *Ammonia Emissions* (AE) indicator. The mineral fertiliser calculation  
350 relies on the average spring temperature, which was 17.2°C computed according to the  
351 methodology. It was obtained from 10 years of data measured at the Experimental Center of  
352 the University of Turin in Carmagnola (TO).

353 The Tier 2 methodology for organic fertiliser addresses three different NH<sub>3</sub> loss phases:  
354 housing, storage, and spreading. As this paper focuses on only cropping systems, ammonia  
355 emissions during housing and storage were not considered. The amount of nitrogen available  
356 for spreading was calculated as N excreted minus N lost during housing and storage. N losses  
357 during housing and storage were calculated by the EMEP methodology, while N<sub>2</sub>O losses  
358 during manure storage were calculated using the IPCC methodology (IPCC 2006), adjusted  
359 with a localized EF value of 0.02 for cattle solid manure (ISPRA, 2011).

360 In the case of imported manure, only the spreading phase was considered. The cattle solid  
361 manure total ammonia nitrogen (TAN) used for calculation was 20% (CRPA, 1993).

362 *GHG Emissions* were calculated per the IPCC methodology (IPCC 2006) and expressed as  
363 CO<sub>2</sub> equivalents. According to the methodology and without a change in land use, the  
364 emissions considered were those from diesel consumption and from direct and indirect N<sub>2</sub>O  
365 losses from agricultural soils. Diesel fuel combustion accounts for CO<sub>2</sub>, CH<sub>4</sub>, and N<sub>2</sub>O  
366 emissions. To calculate those emissions, a diesel density of 0.855 kg l<sup>-1</sup> was used (Bosch,  
367 1996).

368 Direct N<sub>2</sub>O losses consider all the nitrogen added to the system as fertiliser and as crop  
369 residues. A Tier 1 approach was applied because of a lack of specific emission factors.

370 Indirect N<sub>2</sub>O losses were calculated with Tier 2, applying EMEP/EEA methodologies for NH<sub>3</sub>  
371 and NO losses.

372

## 373 2.4 Data analysis

374 The expected grade of the different cropping systems was defined through ranking them from  
375 1 to 4 to represent a progressive environmental sustainability from conventional (1) to  
376 livestock organic (4) cropping systems. Only for pesticides use indicators, ORG and LIV  
377 were set to 3 as in both these two cropping systems chemicals are not permitted in the same  
378 way. The association between the different agro-environmental indicators and the grade  
379 assigned to each cropping system represents the ability of the indicator to correctly grade the  
380 cropping systems and was assessed through Kendall Tau-b rank correlation (Kendall, 1938).  
381 The test was carried out using SPSS ver. 20.

382 To better summarise results and to underline the grading of different cropping system groups,  
383 the indicators were presented as radar graphs, one for driving force indicators and one for  
384 pressure indicators. Radar graphs were elaborated using R software ver. 2.15.1. Each axis  
385 represented an indicator. To evaluate the cropping systems in radar graph, values were  
386 presented as the average of each farm group. Each indicator was rescaled between the  
387 minimum and maximum values.

388 Most indicators indicated higher environmental sustainability with low values. However,  
389 some indicators had opposite meaning. Consequently, to standardise results, the *Number of*  
390 *Crops* and *Net Energy* indicators were multiplied by -1, and *Soil Cover* and *Energy Use*  
391 *Efficiency* were represented as their reciprocals. Finally, gross nutrient balances were  
392 considered as absolute values. Therefore, on the graphs, the cropping systems showing higher  
393 sustainability and lower impact occupy a smaller area.

394 Among driving force indicators *Mineral fertilisers* and *Organic fertilisers* were not presented  
395 in radar graph, since their results were redundant when compared to *N, P, and K fertiliser*  
396 indicators.

397

398 3 Results

399 3.1 Driving force indicators

400 Driving force indicators (Table 6) describe the cropping system characteristics through four  
401 agricultural management aspects: land use, fertiliser use, pesticides use, and energy use.

402 Table 7 represents the ability of each indicator to correctly grade the different cropping  
403 systems through the Kendall  $\tau(b)$  correlation test.

404 *Tillage Practices* allowed to grade the different cropping systems and to differentiate organic  
405 cropping systems from the other two systems (Kendall  $\tau(b)$  -0.87,  $P(\tau)$  0.006). Although  
406 *Number of Crops* presented higher values in organic cropping systems, the grading was not  
407 significant (Kendall  $\tau(b)$  0.60,  $P(\tau)$  n.s.). *Irrigation* demonstrated more homogeneity between  
408 the different farm types and also in this case Kendall correlation was not significant.

409 Fertiliser use clearly separated organic cropping systems from the other two systems as the  
410 former used only organic fertiliser and the latter only mineral. Moreover, LIV showed higher  
411 values than ORG due to farmyard manure application, while INT showed a lower value than  
412 CONV due to RDP restrictions.

413 *N fertilisers* decreased from CONV through INT to ORG systems. Values for LIV were  
414 higher than in INT due to the greater nutrient availability from recycling internal manure. If  
415 LIV is removed from the correlation analysis, the grading of the other systems is significant  
416 (Kendall  $\tau(b)$  is -0.89,  $P(\tau)$  0.017, not shown in table 7). Even though LIV2 stayed within the  
417 170 kg ha<sup>-1</sup> organic regulation limitation, the methodology used to calculate N excreta showed  
418 nitrogen fertiliser input surpassed this limit. *P* and *K fertilisers* were higher in LIV due to tied  
419 N/P and N/K ratios and to the large amount of supplied manure. *P* and *K fertilisers* showed no  
420 trends in the other cropping systems (*P fertilisers* Kendall  $\tau(b)$  0.15,  $P(\tau)$  n.s. and *K fertilisers*  
421 Kendall  $\tau(b)$  0.31,  $P(\tau)$  n.s.).

422 Pesticides were only applied in non-organic cropping systems. *Consumption of Pesticides*  
423 highlighted the low pesticide use in INT *versus* CONV (Kendall  $\tau(b)$  -0.95,  $P(\tau)$  0.004).  
424 *Equivalent Treatments* indicator was also able to grade correctly CONV and INT (Kendall  
425  $\tau(b)$  -0.86,  $P(\tau)$  0.009).

426 The *Number of Practices* was higher on organic farms, both for ORG and LIV, which arose  
427 primarily from the high frequency of operations required for hay production (Kendall  $\tau(b)$   
428 0.69,  $P(\tau)$  0.022). Secondly, the presence of another crop on a portion of the UUA  
429 increased the average practice number.

430 *Energy Input* was higher in CONV and INT than in organic cropping systems (Kendall  $\tau(b)$  -  
431 0.69,  $P(\tau)$  0.022). Figure 2 shows the energy inputs considered and their related values. The  
432 greatest energy inputs were those related to mechanisation and fertiliser use, followed by seed  
433 energy inputs. Pesticides showed very low values.

434 The rank of mechanisation energy input use were, on average, high for CONV and INT,  
435 followed by LIV, and lowest for ORG. Notably, INT1 presented a lower value than LIV.  
436 Fertiliser energy inputs were very high in CONV and INT, very low in ORG, and zero in LIV.  
437 While only a small amount of commercial organic fertiliser was used in ORG, the energy  
438 input necessary for its production was included. The absence of fertiliser energy inputs in LIV  
439 stems from its manure use considered as by-product, and consequently, requiring no energy  
440 input. Seed energy inputs were higher in INT due to an elevated wheat seed use, and highest  
441 in ORG2, in which transplanted tomato seedlings were used.

442

## 443 3.2 Pressure indicators

### 444 3.2.1 Land use

445 *Soil Cover* (Figure 3) was higher in organic cropping systems due to the presence of  
446 meadows, other forages, and double crops (Kendall  $\tau(b)$  0.69,  $P(\tau)$  0.022).

### 447 3.2.2 Fertiliser use

448 Figure 4 lists the nutrient inputs and their nutrient gross balances for N, P, and K. The main N  
449 inputs were mineral fertilisers for CONV and INT, biological fixation for ORG, and organic  
450 fertilisers for LIV. The *Gross N Balances* showed CONV had a higher surplus than the other  
451 systems due to its high input use and low off-take. The second highest surplus was found in  
452 INT (approximately 50 kg N ha<sup>-1</sup>) as opposed to the low LIV values (near zero). LIV  
453 underwent higher fertiliser inputs and legume fixation, but it had a lower surplus due to more  
454 crop off-take from meadow and double crop presence. Low levels of inputs in ORG led to a  
455 negative *Gross N Balance*. In general this indicator is able to correctly grade the different  
456 cropping systems (Kendall  $\tau(b)$  -0.77,  $P(\tau)$  0.011).

457 *Gross P Balances* were about zero or negative. CONV and INT presented higher variability  
458 within their groups, which made differentiation between them impossible. ORG had the most  
459 negative values due to its lower fertiliser input level. For LIV, the balances were slightly  
460 negative due to a high input of manure fertilisation. The lack of a correct grading was  
461 confirmed by Kendall correlation that was not significant.

462 *Gross K Balances* were positive for INT, negative for CONV1, and lower for CONV *versus*  
463 INT. GKB were negative for all organic cropping systems. The very low fertiliser input levels  
464 in ORG, was reflected in a very low GKB also. LIV too had a negative balance; its higher  
465 level of potassium input partially compensated the off-take. Kendall correlation was not  
466 significant, thus confirming the high variability of GKB (Kendall  $\tau(b)$  0.39,  $P(\tau)$  n.s.).

467

### 468 3.2.3 Pesticide use

469 *Load Index* graded correctly CONV and INT (Figure 5) for each class of non-target organism  
470 (algae Kendall  $\tau(b)$  -0.95,  $P(\tau)$  0.004, fishes Kendall  $\tau(b)$  -0.76,  $P(\tau)$  0.021, bees Kendall  $\tau(b)$  -  
471 0.86,  $P(\tau)$  0.009, earthworms Kendall  $\tau(b)$  -0.76,  $P(\tau)$  0.021, mammals Kendall  $\tau(b)$  -0.86,

472  $P(\tau)$  0.009, birds Kendall  $\tau(b)$  -0.95,  $P(\tau)$  0.004). *Load Index* trended in a like pattern on all  
473 farms for each class of non-target organism. The values were lower for birds and mammals,  
474 while the highest values were for fishes and algae. The *Environmental Impact Quotient* (EIQ)  
475 differentiated the cropping systems better, and it made evident a lower potential impact of  
476 pesticide use in INT than in CONV (Figure 6) (Kendall  $\tau(b)$  -0.95,  $P(\tau)$  0.004). Analysis of  
477 the three *EIQ* components (farmers, consumers and environment) trended like total *EIQ*. INT  
478 had the lowest impact values in each. The environmental component was the most impacted;  
479 consumers were impacted the least.

480

#### 481 3.2.4 Energy use

482 Figure 7 presents *Net Energy* and *Energy Use Efficiency* indicator results. *Net Energy* was  
483 higher for LIV, with values nearly double those of the other cropping systems. The incorrect  
484 grading was confirmed by a not significant Kendall correlation. *Energy Use Efficiency*  
485 resulted in similar values for CONV and INT. All organic cropping systems had higher values  
486 of *Energy Use Efficiency*, and LIV systems had the highest (Kendall  $\tau(b)$  0.72,  $P(\tau)$  0.011).

487

#### 488 3.2.5 Gaseous emissions

489 In arable cropping systems, the *Ammonia Emissions* (Figure 8) indicator trended similarly to  
490 nitrogen fertiliser inputs; that is, values decreased from CONV through INT to ORG. LIV  
491 showed the highest values. Kendall correlation was not significant. Figure 9 displays *GHG*  
492 *Emissions* as the sum of two sources, expressed in CO<sub>2</sub> equivalent. The total *GHG Emissions*  
493 presented values that distinguished between cropping system groups. The highest values were  
494 in CONV; INT and LIV had similar intermediate values, and the lowest values were those  
495 calculated for ORG (Kendall  $\tau(b)$  -0.62,  $P(\tau)$  0.041). N<sub>2</sub>O emissions trended like the total  
496 *GHG emissions*.

497

## 498 4 Discussion

499 The grading of the cropping systems has been analysed according to the indicator groups to  
500 describe the existing relationships between input levels (driving force indicators) and  
501 environmental pressures (pressure indicators). Results were compared with the expected  
502 grading derived from the different intensification levels as defined by regulations.

503

### 504 4.1 Land Use

505 Although biodiversity is an important issue that should be analysed, the majority of the crops  
506 here explored were renewed each year with industrial selected seeds and therefore within  
507 species diversity is not expected. Meadows are also usually renewed each 3-5 years, and only  
508 in one case a small surface is permanent grassland. The analysis of within-species diversity  
509 could give interesting information that completes the analysis of crop biodiversity, but the  
510 level of detail required to obtain this information is beyond the aims of this works, that is to  
511 analyse data collected through interviews and database.

512 The analysed farms mainly cultivated arable crops typical of the study area: maize, winter  
513 cereals, and soybean (Sacco et al., 2003; Bassanino et al., 2007). Organic cropping systems,  
514 however, varied their crop rotations more to include meadows, double crops, and legumes  
515 (soybean, bean, lucerne). The fact that the organic systems had a larger number of crops in  
516 rotation met several needs: to control pests, to increase N addition through N fixation, and to  
517 grow fodder crops in the case of livestock production systems.

518 Lampkin (2002) reported that crop rotation helped control pests in organic systems, and a  
519 recent review by Gomiero et al. (2011) showed that crop rotation is an effective farming  
520 practice to reduce the negative impact of weeds. European regulation 834/2007/EC (EC,  
521 2007) also suggests crop rotation as one preventive measure to maintain plant health.

522 Introducing legumes into the crop rotation is aimed at increasing N supply into the system as  
523 crop uptake of N fixing crops is, at the least, balanced by N biological fixation. Practices such  
524 as these allow systems to overcome the imposed 170 kg N ha<sup>-1</sup> limit on fertiliser use.

525 All organic systems introduce meadows into the farm area. On livestock organic farms, they  
526 are necessary to feed animals; in arable organic farms, they produce hay, which can be sold to  
527 livestock organic farms or exchanged for manure fertiliser. The presence of meadows (3-5  
528 year duration) permits a no-till area to be present without adopting no-tillage practices.  
529 Furthermore, meadows and double crops lead to longer periods of soil cover during the year.  
530 These two aspects have a minor environmental impact, and result in higher sustainability  
531 characteristic of organic cropping systems *versus* the less sustainable conventional and  
532 integrated cropping systems.

533 The DM yields declared by organic system farmers are generally in the range of conventional  
534 and integrated cropping systems. However, according to the literature (Kirchmann and Ryan,  
535 2005; Eltun et al., 2002; Basset-Mens and van der Werf, 2005), organic cropping systems  
536 usually produce less than conventional cropping systems, although manure fertilisation could  
537 reduce the yield gap (Kirchmann and Ryan, 2005). The analysed cropping systems were  
538 selected for their regional representativeness. As such, they came from a wide area  
539 characterised by different pedological and climatic conditions with high production variability  
540 that makes crop DM yield comparisons not feasible. Consequently, indicators were calculated  
541 only per unit of surface and not per unit of production. An assessment per unit of production  
542 could give additional information about the sustainability of the different systems, but  
543 requires more homogeneous pedological and climatic conditions.

544 When the land use pressure indicators were employed to grade the different farms organic  
545 cropping systems were shown to impact the environment less than conventional and  
546 integrated cropping systems.

547

## 548 4.2 Fertilisers use

549 Organic cropping systems that paired manure with meadows in the crop rotation showed  
550 higher soil organic matter content. Between the two organic cropping systems considered,  
551 livestock systems had the highest soil organic matter values consequent to their higher  
552 manure input. Similar results were observed by Bertora et al. (2009) in manure-based  
553 conventional and integrated cropping systems and by Fließbach et al. (2007) in livestock-  
554 based bio-organic and bio-dynamic cropping systems.

555 In livestock organic cropping systems, the manure amount applied depends on the stocking  
556 rate. Per European and regional regulations, N input is calculated from stocking rate using  
557 tabular data, while respecting the 170 kg N ha<sup>-1</sup> limit. However, in the present study, the real  
558 amount of N supplied in the livestock organic cropping systems has been calculated using  
559 nutrient mass balance, which resulted in a higher N input, even in farms that complied with  
560 European regulations.

561 As livestock organic farms manure fertilisation is calibrated on N loads, P and K inputs are  
562 defined by N/P and N/K ratios in manure and not on actual crop need (Bassanino et al., 2011).  
563 For this reason, P and K amounts were the highest in the livestock organic cropping systems  
564 (Spear et al., 2003; Bassanino et al., 2011).

565 Arable organic cropping systems used the lowest levels of fertiliser inputs not only because it  
566 is difficult to retrieve manure, but also because of the high cost of organic fertiliser. On both  
567 of the farms of this group, legume fixation was the main source of N, which made it essential  
568 to compensate for the very low N from fertilisers.

569 Therefore, in terms of N fertiliser inputs, the farms decreased in intensity from conventional  
570 to integrated to arable organic systems. Livestock organic cropping systems demonstrated an  
571 input level similar to integrated cropping systems. Conventional and integrated system

572 differences related to fertiliser use limits defined by the RDP for integrated cropping systems.  
573 If the analysis had considered all N additions, including N from legume fixation, the trend  
574 would be altered to show the highest values for conventional and livestock organic systems,  
575 and the lowest values for integrated and arable organic systems.

576 Gross nutrient balances did not always trend like nutrient inputs as crop off-take introduced  
577 large differences among farms types. N balance of conventional, integrated, and arable  
578 organic systems reflected the trend of N fertiliser input. Although livestock organic systems  
579 showed higher fertiliser input with the highest input derived from legume fixation, they  
580 produced lower surpluses than did integrated and conventional systems due to large crop off-  
581 takes from meadows and double crops. Arable organic systems were the only that resulted in  
582 negative N balances.

583 P balances were negative for all systems, which helped to offset the large soil P content.  
584 Arable organic systems showed the most negative balances due to their low nutrient supply.  
585 Livestock systems had the highest input from their high manure fertilisation, but it failed to  
586 compensate for the high off-take from the presence of meadows.

587 Finally, the K balances clearly diverged between organic and non-organic cropping systems;  
588 in fact, they showed positive values only in the latter group. For the studied area, Bassanino et  
589 al. (2011) demonstrated that manure fertilisation usually balances K off-take, however, they  
590 found wide crop variances (positive balances for maize and negative balances for meadows).  
591 This variability also explains the negative K balances of livestock organic systems given their  
592 high meadow portion. Torstensson et al. (2006), who studied the nutrient use efficiencies of  
593 organic and conventional cropping systems in Sweden, found negative K balances in all  
594 cropping systems, especially in animal manure organic systems ( $-36 \text{ kg K ha}^{-1}$  per year). This  
595 result was attributed to the large amounts of K taken up by forage crops.

596

597 4.3 Pesticide use

598 The organic farms analysed in this work did not use pesticides. *Consumption of Pesticides*  
599 allowed the farms to be graded according to their relative intensification levels, with  
600 conventional cropping systems using higher input quantities. Integrated cropping systems fell  
601 below these levels due to limits set by the RDP.

602 *Load Index* underlined the impact on non-target organisms shared across the cropping  
603 systems. In all cases, the lowest impacts were on birds and mammals, while the highest  
604 impacts were on the aquatic environment (fishes and algae). Bechini and Castoldi (2009) had  
605 also indicated that algae have the highest *Load Index* values.

606 The *Environmental Impact Quotient* clearly distinguished between conventional (higher  
607 values) and integrated cropping systems (lower values). Integrated system pesticide limits,  
608 introduced and monitored regionally by the RDP, have been confirmed by the IPLA (2012) to  
609 reduce the potential impact of pesticide applications. Farmer and environmental components  
610 of the indicator made evident the differences between conventional and integrated systems.  
611 The main impact was to the environment in all systems, but integrated management did  
612 severely lessen its environmental impact achieving the goal of the regulation.

613

614 4.4 Energy use

615 Fertilisation and mechanisation are the two main components that characterise *Energy Input*  
616 on the eight farms, in agreement with other studies (Alluvione et al., 2011; Meul et al., 2007;  
617 Fumagalli et al., 2011). According to Castoldi and Bechini (2010), cropping system energy  
618 input depends mainly on the crops in the system and their relative shares of the farm surface.  
619 The highest energy inputs correspond to maize, followed by meadows, and finally to winter  
620 cereals. Notwithstanding, energy input values are also closely linked to the fertilisation  
621 management used for each crop (Bechini and Castoldi, 2009).

622 In this study, *Energy Input* enabled system grading by expected intensification level. The  
623 lowest level, recorded in organic cropping systems, depended mostly on two factors — the  
624 presence of meadows and organic fertilisation that has a zero energy cost (as a by-product of  
625 breeding activity). The energy input derived from mechanisation was also low on organic  
626 farms due to the very low fuel amount required for tedding, raking, and baling forage crops,  
627 even if they used a great number of passes. In conventional and integrated cropping systems,  
628 fertiliser and mechanisation inputs differentiated the two and proved conventional cropping  
629 systems to have the highest values. Alluvione et al. (2011) demonstrated this same rank in a  
630 field experiment conducted in the same agricultural area in two cropping systems fertilised  
631 with only mineral fertilisers. Cruse et al. (2010) conducted a six-year study that compared  
632 energy use in a conventional two-year rotation system (maize and soybean) to two low input  
633 cropping systems that used more diverse crops (maize, soybean, small grains, and red clover  
634 or lucerne), manure, less fertiliser and herbicides. They found that the two low-input systems  
635 used 23% to 56% less fossil energy than did the conventional system.

636 The driving force indicator *Number of Practices* showed unexpected and contradictory results  
637 relative to *Energy Input*. The high number of operations associated with forage field drying in  
638 hay production yielded high *Number of Practices* for organic cropping, yet the relatively  
639 small amount of fuel consumed for each pass kept *Energy Input* low.

640 The two pressure indicators, *Net Energy* and *Energy Use Efficiency*, identified three different  
641 situations:

- 642 - high *Net Energy* and high *Energy Use Efficiency* in livestock organic systems;
- 643 - low *Net Energy*, but high *Energy Use Efficiency* in arable organic systems;
- 644 - low *Net Energy* and low *Energy Use Efficiency* in conventional and integrated  
645 systems.

646 The higher values of *Energy Use Efficiency* recorded in the organic cropping systems mainly  
647 depend on the low *Energy Inputs* that characterise these two systems. Moreover, the presence  
648 of meadows, particularly lucerne, increased energy output due to its high DM yield.  
649 Furthermore, double crops increased energy output with a small energy input. Differences  
650 between livestock and arable organic systems also related to the higher share of energy-  
651 producing meadows and silage crops in livestock systems. The lower *Net Energy* and *Energy*  
652 *Use Efficiency* calculated for conventional and integrated systems related to their higher  
653 *Energy Input*. The similarity of *Energy Input* and energy output in the two systems did not  
654 permit distinction between them.

655

#### 656 4.5 Gaseous emissions

657 *Ammonia Emissions* showed a trend like that of N fertilization, but no correlation with system  
658 grading. The EMEP/EEA methodology (EEA, 2009) explains that mineral fertiliser ammonia  
659 comes from urea that has emission values similar to manure, whereas ammonia emissions  
660 from other mineral fertilisers are lower. Livestock farms had the highest emission values due  
661 to their exclusive use of manure (high emission factor).

662 *GHG Emissions* correctly graded the cropping systems. The highest ranked system was  
663 conventional and the lowest ranked was arable organic; livestock organic systems ranked in  
664 the middle of the two. Although livestock and integrated systems had similar N fertilisation  
665 values, livestock systems yielded lower emission values due to the presence of meadows that  
666 are characterized by lower crop residue.

667

#### 668 4.6 Radar

669 Radar graphs described and made evident the impact of the different cropping systems  
670 (Bockstaller et al., 1997; Sattler et al., 2010). They made it easy to understand how driving

671 forces and their consequent pressures determine the grade of the different systems. Figure 10  
672 shows two radar graphs, one for driving force indicators and one for pressure indicators. The  
673 indicator *Irrigation* varied highly among and within the cropping system groups because of  
674 differing pedological and climatic conditions; at the same time, it is unaffected by the  
675 different intensification levels. As it was unable to differentiate farms based on their intensity  
676 levels, it was excluded from the graph. Among pressure indicators, *Load Index* values were  
677 not represented as *Environmental Impact Quotient* better graded the different farms.

678 The two radar graphs show that the grade of the driving forces is not necessarily reflective of  
679 the grade of the pressures. The graphs underscore that most indicators graded the cropping  
680 systems according to their defined intensification level. However, some indicator groups  
681 graded the cropping systems differently in driving force and pressure graphs.

682 Conventional systems demonstrated the worst grade of driving force indicators, while the best  
683 were related to arable organic cropping systems. Analysing the graph as a whole, it is not  
684 possible to clearly discriminate integrated from livestock organic systems as both presented  
685 intermediate values, although they graded differently on single indicators. Conventional  
686 cropping systems presented the highest impact from pressure indicators, followed by  
687 integrated cropping systems. In this case, arable organic cropping systems presented higher  
688 impact than did livestock systems. This suggests that pressure indicators reflected  
689 intensification grading better than driving force indicators.

690 The agro-environmental indicator set analyses underlined two main correlated factors, which  
691 allowed differentiation of intensification levels among the cropping systems. First, legal input  
692 limits and management practices do reflect on intensification levels. Second, organic  
693 production regulations that defined management practices, in particular the presence of  
694 meadows and use of organic fertilisers, do influence those systems, and could similarly

695 influence the environmental performance of other cropping systems if practiced. This  
696 potential calls for evaluation on how to improve regulations to increase system sustainability.  
697 The goal to design and develop usable tools to assess the environmental impact of agricultural  
698 policy has grown in recent years. Improvements in agro-environmental policy evaluation  
699 standards, direct support schemes, and recommendations from the Common Monitoring and  
700 Evaluation Framework of the European Commission, which requires Member States to assess  
701 the impacts of their RDP (Schuh et al., 2011), have converged to focus on the same goal.  
702 Member States often use routine administrative data to monitor the effectiveness of agro-  
703 environmental measures, but this often does not reliably measure the environmental impacts  
704 of the policy. Adoption of agro-environmental measures does not guarantee that  
705 environmental standards will be attained (Mauchline et al., 2012).

706 The indicator set in this research was selected to allow comparison and grading of farm  
707 management intensities in order to assess environmental pressures and to inform decision-  
708 and policy-makers on how to manage, implement, and evaluate *ex post* agro-environmental  
709 measures and policy impacts. Following the recommendations of Bechini and Castoldi  
710 (2009), who suggested that indicators be simple, synthetic, and derived from data that can be  
711 easily obtained, input variables for the calculation of selected indicators should be collectable  
712 in farm interviews by questionnaire and/or data should be obtainable from official farm  
713 databases, thus coupling scientific soundness with cost-effectiveness of the process.

714

## 715 5 Conclusion

716 The result of this study showed that the indicator set presented was mostly able to correctly  
717 grade cropping system intensification levels, and that it could evaluate their agro-  
718 environmental sustainability. However, in some cases, the expected grade did not result. This  
719 work showed that this is not due to indicator fault, but rather that some analysed variables did

720 not reflect the intensification expected. This phenomenon happened mainly for driving force  
721 indicators.

722 The analysis also showed that higher input levels do not always reflect higher environmental  
723 pressure. Therefore, outside ethical aspects that are not in the aim of this work, regulations  
724 should be preferable based on pressure indicator thresholds instead of on system inputs.

725

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1034

1035 Tables

1036

1037 Table 1 – Surface and soil characteristic of the eight farms.

1038

	State indicator	CONV1	CONV2	INT1	INT2	ORG1	ORG2	LIV1	LIV2
Surface	UAA (ha)	36	84	50	83	24	19	35	54
Soil quality	Texture	silt loam	loam	silt loam	silt loam	silt loam	silt loam	loam	loam
	pH	6.6	5.9	6.3	5.6	8.3	6.1	5.9	6.9
	Organic matter (%)	3.1	1.7	1.2	1.9	2.0	2.3	4.0	3.6
	N (%)	0.21	0.10	0.08	0.14	0.14	0.13	0.23	0.24
	C/N	8.3	9.7	9.3	7.8	8.7	10.2	10.0	8.7
	P (ppm)	20.3	66.3	35.0	30.8	27.3	19.3	34.8	27.8
	K (meq 100g <sup>-1</sup> )	0.15	0.21	0.15	0.15	0.24	0.08	0.15	0.09

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1043 Table 2 – Crop DM yield (t ha<sup>-1</sup>) of the eight farms studied.

1044

Product	CONV1	CONV2	INT1	INT2	ORG2	ORG2	LIV1	LIV2
Maize grain	11.3	11.3	7.9	10.1			8.8	
Maize silage							17.3	
Maize straw							7.3	
Wheat	3.6		5.0	4.4	4.5	5.4		
Wheat straw	2.3		4.1	2.3	4.2	2.9		
Lucerne					8.1	15.0		13.7
Soybean (II) <sup>a</sup>		3.9		3.2		3.5 (3.3)		
Meadow							12.0	
Barley						4.8	4.1	4.4
Barley straw						2.9	3.4	5.7
Switchgrass								4.2
Bean					1.6			
Italian ryegrass					6.8			
Sorghum silage							10.2	
Grassland						3.4		
Tomato						6.5		
<sup>a</sup> second crop								

1045

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1047

1048 Table 3 – Coefficients used to calculate Energy Input, Net Energy and Energy Use Efficiency.

1049 Energy equivalent represents the energy embedded in each input/output product.

Input/Output		U.M.	Energy equivalent
<b>Crop</b>	<b>Product</b>		
Maize	grain <sup>a</sup>	MJ kg <sup>-1</sup> DM	18.92
	silage <sup>b</sup>		17.9
	straw <sup>a</sup>		18.67
	seed <sup>b</sup>		113.2
Wheat	grain <sup>a</sup>		18.42
	straw <sup>a</sup>		18.17
	seed <sup>b</sup>		31.3
Lucerne	hay <sup>c</sup>		18.84
	seed <sup>d</sup>		31.4
Soybean	grain <sup>a</sup>		23.65
	seed <sup>b</sup>		40.6
Meadow	hay <sup>b</sup>		17.6
	seed <sup>d</sup>		31.3
Barley	grain <sup>b</sup>		18.4
	straw <sup>b</sup>		16.8
	seed <sup>b</sup>		31.4
Switchgrass	hay <sup>d</sup>		17.2
	seed <sup>d</sup>		31.3
Bean	grain <sup>d</sup>		16.74
	seed <sup>d</sup>		40.6
Italian ryegrass	hay <sup>b</sup>	17.2	
	seed <sup>b</sup>	31.3	
Sorghum	silage <sup>d</sup>	18	
	seed <sup>d</sup>	31.4	
Grassland	hay <sup>b</sup>	17.6	
Tomato	fruit <sup>e</sup>	MJ kg <sup>-1</sup> FM	1.3
	seedling <sup>f</sup>	MJ plant <sup>-1</sup>	0.28
<b>Fertiliser</b>			
N- NH <sub>4</sub> <sup>b,g</sup>		MJ kg <sup>-1</sup>	39
N-ureic <sup>b,g</sup>			48
N-NO <sub>3</sub> <sup>b,g</sup>			32
N-other <sup>h</sup>			50
P <sub>2</sub> O <sub>5</sub> <sup>b,g</sup>			4
K <sub>2</sub> O <sup>b,g</sup>			5
FPT <sup>h</sup> for N fertilisers <sup>i</sup>			1.5
FPT <sup>h</sup> for P fertilisers <sup>i</sup>			9.8
FPT <sup>h</sup> for K fertilisers <sup>i</sup>			7.3
FPT <sup>h</sup> for NP fertilisers <sup>i</sup>			5.7
FPT <sup>h</sup> for other fertilisers <sup>i</sup>			6
<b>Pesticide</b>			
Herbicides <sup>a</sup>		MJ kg <sup>-1</sup> a.i.	264
Fungicides <sup>a</sup>			168
Insecticides <sup>a</sup>			214
Formulation <sup>a</sup>			20
Packaging <sup>a</sup>			2
Transport <sup>a</sup>		MJ kg <sup>-1</sup>	1.3
<b>Other</b>			
Diesel <sup>a</sup>		MJ l <sup>-1</sup>	46.9
Lubricants <sup>h</sup>		MJ l <sup>-1</sup> diesel	3.6
Machinery energy embeddec			12
<sup>a</sup> Alluvione et al., 2011	<sup>f</sup> Canakci et al., 2005		
<sup>b</sup> Bechini and Castoldi, 2009	<sup>g</sup> Kongschaug, 1998		
<sup>c</sup> Fluck, 1992	<sup>h</sup> Dalgaard et al., 2001		
<sup>d</sup> Estimated	<sup>i</sup> Castoldi and Bechini, 2006		
<sup>e</sup> Meul et al., 2007			
<sup>h</sup> FPT = Formulation, Packaging and Transportation			

1050

1051 Table 4 – Diesel consumption for the different farm practices.  
 1052

Operation	l ha <sup>-1</sup> (min-max)
chisel plowing	15-32
combined ridging-fertilisation	14
combined row cultivation-fertilisation	4
combined sowing-disking	12-14
combined sowing-fertilisation	12-14
combined sowing-pesticides treatment	6
cutting	5
drying	38-210
fertilisation	2-20
harrowing	8-26
harvesting	17-35
hay spreading	4-5
irrigation	5-185
laser levelling	9-23
pesticide treatment	3-9
plowing	16-39
ridging	4
rolling	3-4
rotary hoe	46
rototilling	7-25
row cultivation	4-9
silaging	17-29
sowing	7-26
straw harvest	4-22
straw shredding	8-30
tine arrowing	3-6
transplanting	24
windrowing	4-6

1053 Table 5 – Coefficients used to calculate the nutrient balance crop off-take.  
 1054  
 1055  
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Crop	Product	N (%DM)	P (%DM)	K (%DM)
Maize	grain <sup>a</sup>	1.70	0.35	0.67
	silage <sup>a</sup>	1.20	0.22	1.00
	straw <sup>a</sup>	0.70	0.13	1.50
Wheat	grain <sup>a</sup>	2.30	0.39	0.50
	straw <sup>a</sup>	0.60	0.09	1.25
Lucerne	hay <sup>a</sup>	2.80	0.31	1.83
Soybean	grain <sup>a</sup>	6.70	0.74	2.25
Meadow	hay <sup>a</sup>	2.20	0.35	2.58
Barley	grain <sup>a</sup>	2.00	0.35	0.83
	straw <sup>a</sup>	0.60	0.09	1.08
Switchgrass	hay <sup>b</sup>	1.50	0.35	2.25
Bean	grain <sup>a</sup>	6.20	0.96	3.42
Italian ryegrass	hay <sup>a</sup>	1.50	0.35	2.25
Sorghum	silage <sup>a</sup>	0.90	0.13	0.83
	grain <sup>a</sup>	1.80	0.52	1.33
Grassland	hay <sup>a</sup>	2.20	0.35	2.08
Tomato	fruit <sup>b</sup>	2.50	0.18	4.83
Generic seeds <sup>c</sup>		1 <sup>d</sup>	1 <sup>d</sup>	3 <sup>d</sup>
<sup>a</sup> Grignani et al., 2003				<sup>d</sup> kg ha <sup>-1</sup>
<sup>b</sup> Estimated				
<sup>c</sup> Nielsen and Kristensen, 2005; Schröder et al., 1996				

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1058 Table 6 – Driving force indicators determined for the eight farms.

1059

Indicator group	Driving force indicator	CONV1	CONV2	INT1	INT2	ORG1	ORG2	LIV1	LIV2
Land use	Number of Crops	2	2	2	3	4	6	4	3
	Tillage Practices (% UAA)	100	100	100	100	73	85	70	28
	Irrigation (% UAA)	55	100	0	68	81	37	60	0
Fertiliser use	Mineral fertilisation (kg ha <sup>-1</sup> )	771	1180	694	473	0	0	0	0
	Organic fertilisation (kg ha <sup>-1</sup> )	0	0	0	0	1977	8710	25163	33524
	N fertilisation (kg ha <sup>-1</sup> )	222.7	310.4	163.4	123.1	11.1	42.7	158.5	214.6
	P fertilisation (kg ha <sup>-1</sup> )	17.2	31.7	25.3	13.4	3.8	16.7	79.5	85.6
Pesticides use	K fertilisation (kg ha <sup>-1</sup> )	32.8	121.0	131.0	68.9	10.6	47.2	167.9	257.4
	Consumption of Pesticides (kg a.i. ha <sup>-1</sup> )	1.5	2.2	0.8	0.5	-	-	-	-
	Equivalent Treatments	3.3	2.2	1.7	2.7	-	-	-	-
Energy use	Number of Practices	10.9	11.4	11.4	10.1	13.9	16.3	17.0	22.5
	Energy Input (GJ ha <sup>-1</sup> )	30.6	40.2	25.5	31.9	9.4	20.0	13.1	15.3

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1063 Table 7 – Kendall's tau b values of correlation between indicator grading against expected  
 1064 grading. Expected grading correspond to CONV = 1; INT = 2; ORG = 3; LIV = 4 for all  
 1065 indicators except for pesticides use indicators where ORG and LIV = 3.  
 1066

Indicator group	Indicators	Kendall's tau_b	Sig.
<b>Driving force indicators</b>			
Land use	Number of Crops	0.60	n.s.
	Tillage Practices	-0.87	0.006
	Irrigation	-0.27	n.s.
Fertiliser use	Mineral fertilisers	-0.87	0.006
	Organic fertilisers	0.87	0.006
	N fertilisers	-0.39	n.s.
	P fertilisers	0.15	n.s.
	K fertilisers	0.31	n.s.
Pesticides use	Consumption of Pesticides	-0.95	0.004
	Equivalent Treatment	-0.86	0.009
Energy use	Number of Practices	0.69	0.022
	Energy Input	-0.69	0.022
<b>Pressure indicators</b>			
Land use	Soil Cover	0.69	0.022
Fertiliser use	Gross N Balance	-0.77	0.011
	Gross P Balance	0.00	n.s.
	Gross K Balance	0.39	n.s.
Pesticide use	Load Index algae	-0.95	0.004
	Load Index fishes	-0.76	0.021
	Load Index bees	-0.86	0.009
	Load Index earthworms	-0.76	0.021
	Load Index mammals	-0.86	0.009
	Load Index birds	-0.95	0.004
	Environmental Impact Quotient	-0.95	0.004
Energy use	Net Energy	0.31	n.s.
	Energy Use Efficiency	0.77	0.011
Gaseous emissions	Ammonia emissions	0.00	n.s.
	GHG emissions	-0.62	0.041

1067

1068 Figures

1069

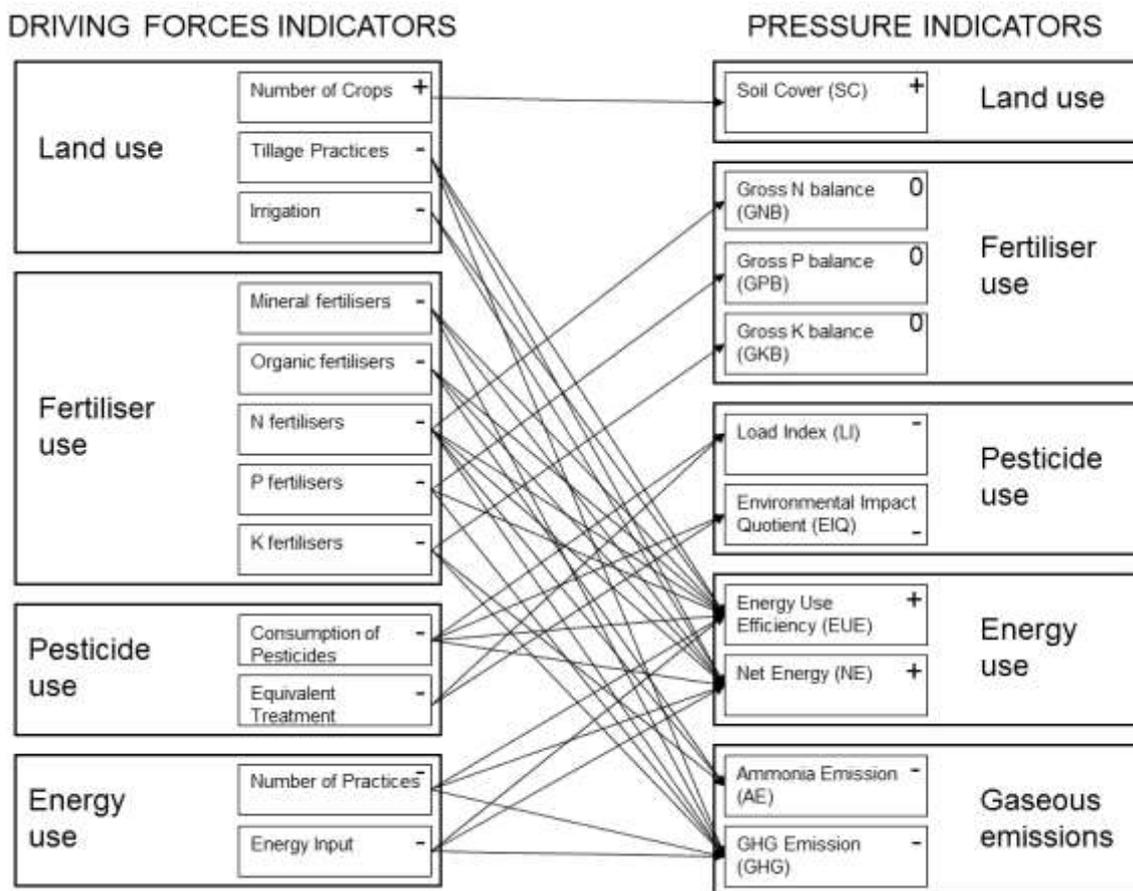
1070 Figure 1 – Relationships between driving force indicators and pressure indicators. The symbol

1071 reported for each indicator specifies the optimal value of the indicator: “+”

1072 sustainability is higher when the indicator is high; “-” sustainability is higher when

1073 the indicator is low; “0” sustainability is higher when the indicator is zero.

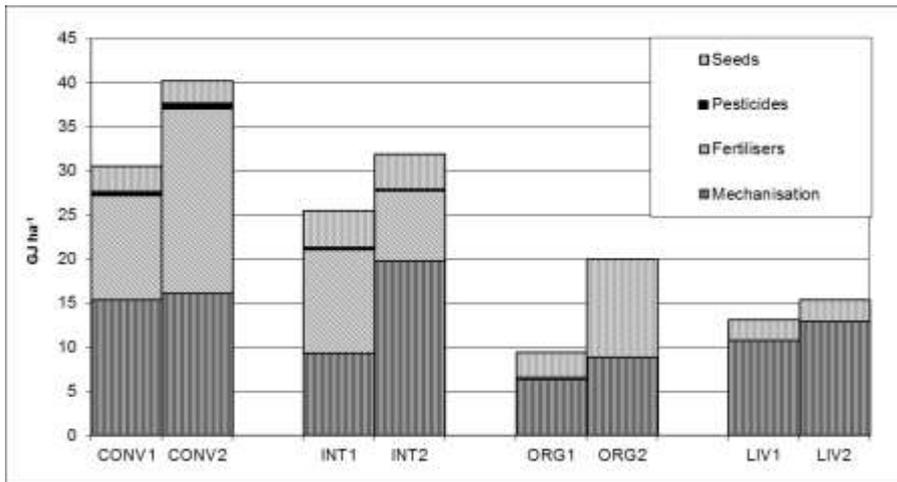
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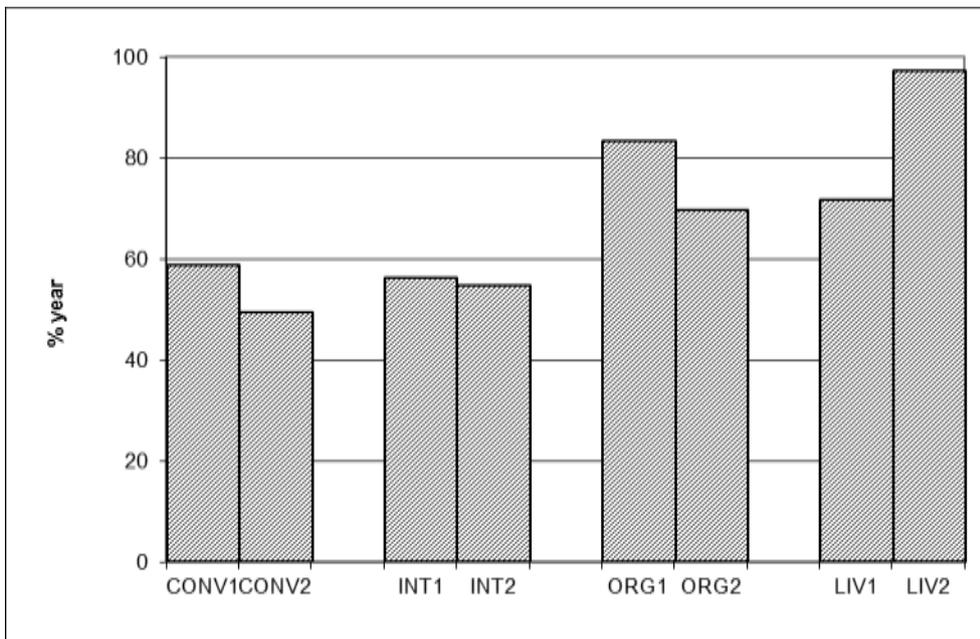
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1077 Figure 2 – Energy Inputs.  
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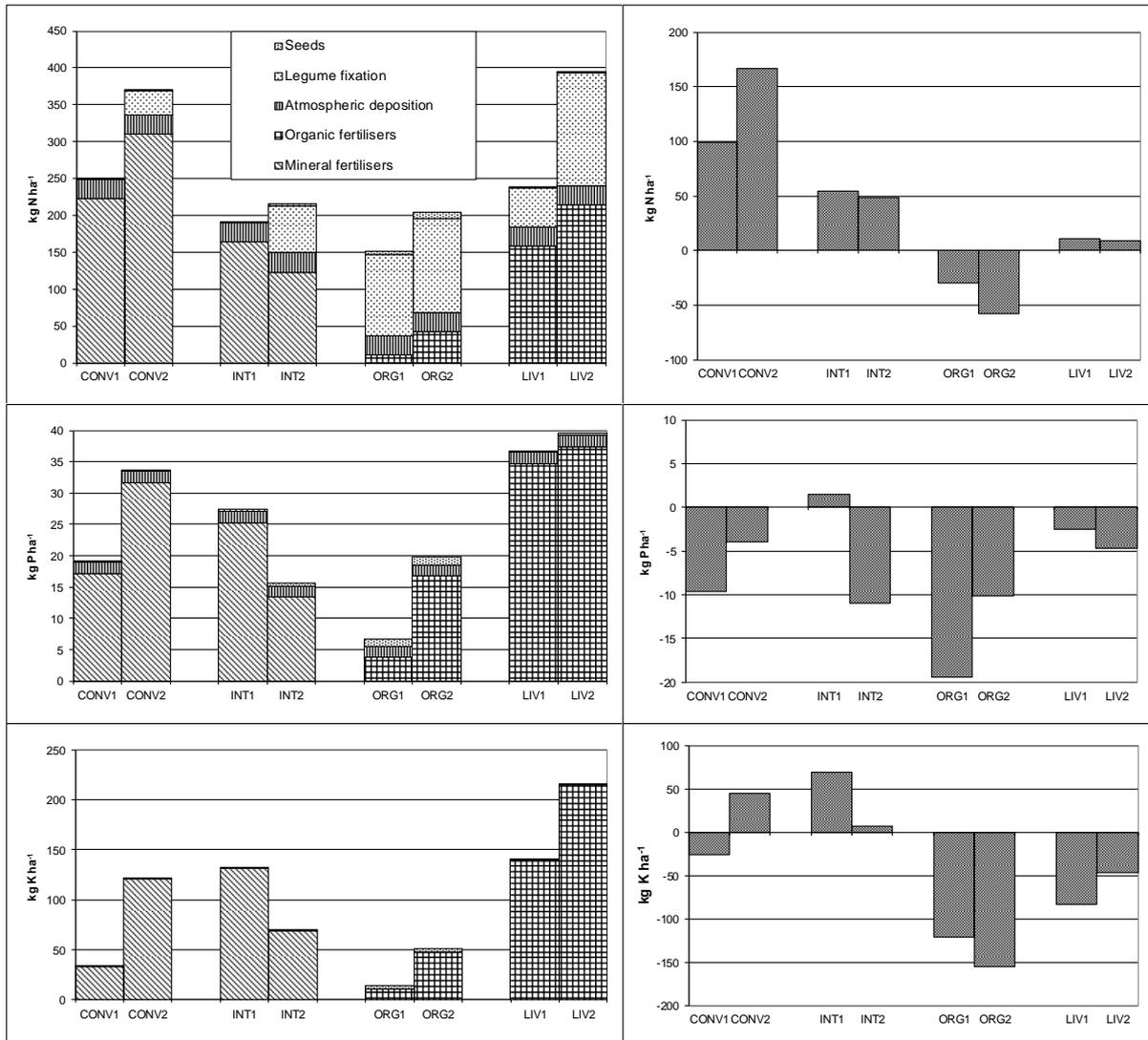


1079 Figure 3 – Percentage of the year with soil cover.  
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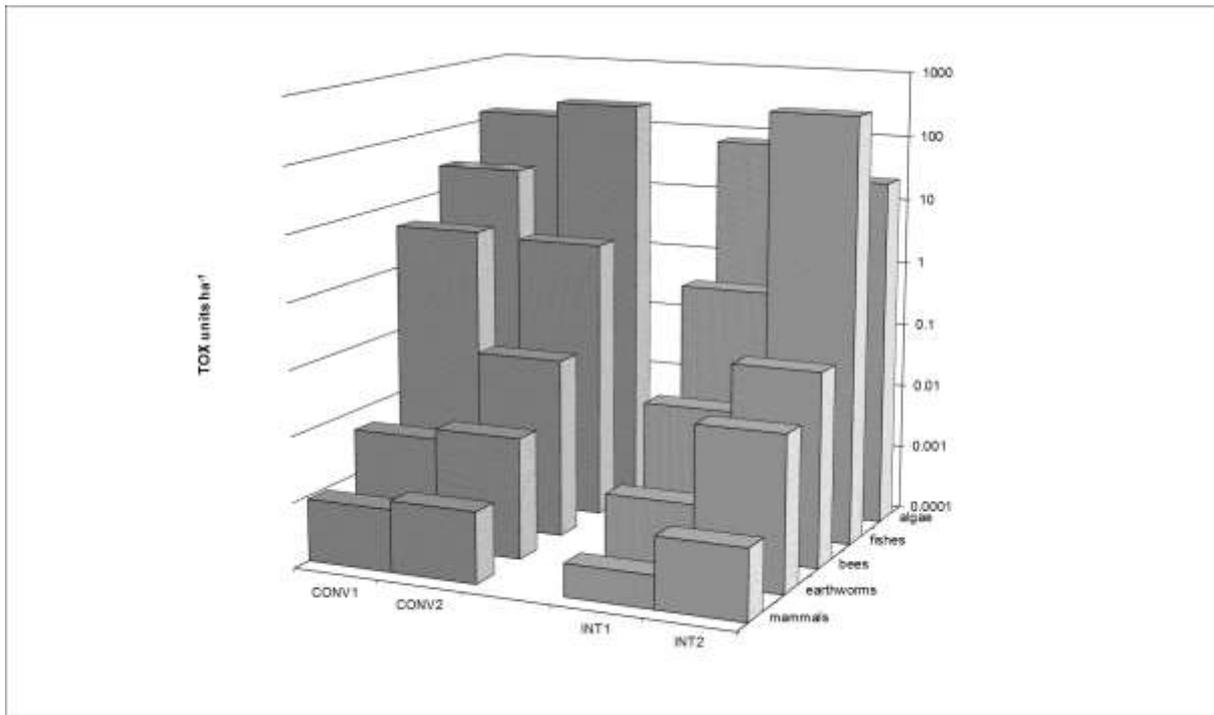
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1086 Figure 4 – N, P, and K inputs (left) and gross nutrient balance (right).  
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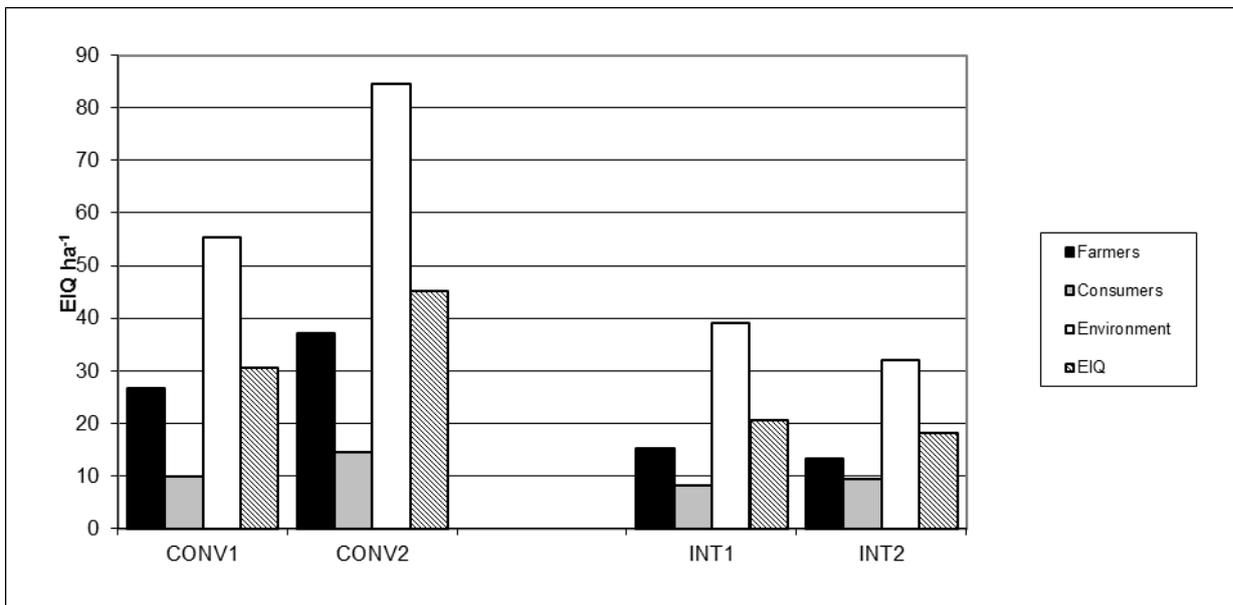


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1091 Figure 5 – Load Index for different non-target organisms.

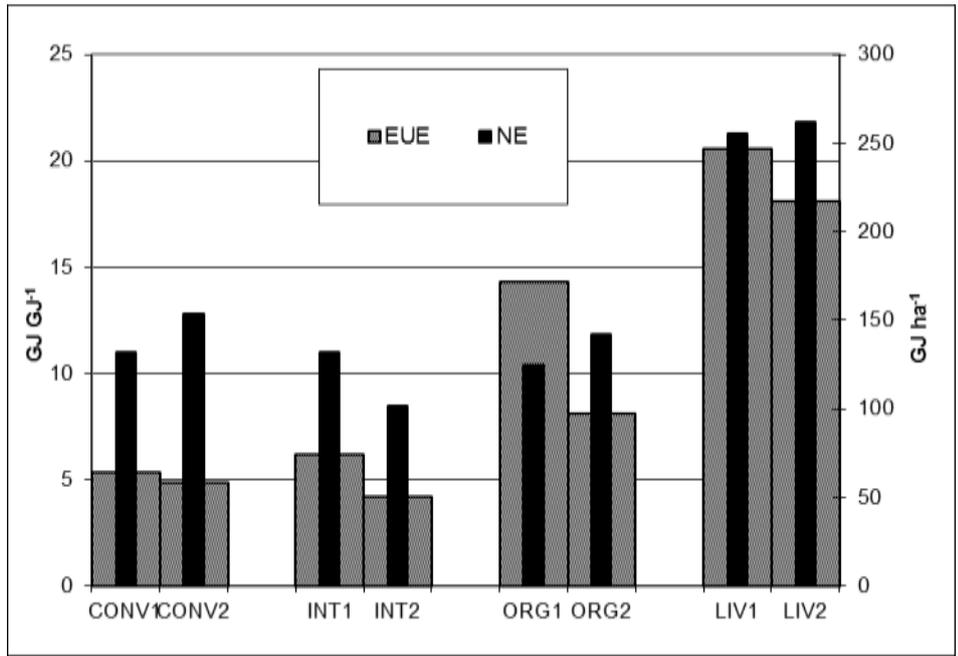


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1093 Figure 6 – Different components of Environmental Impact Quotient (EIQ).  
1094

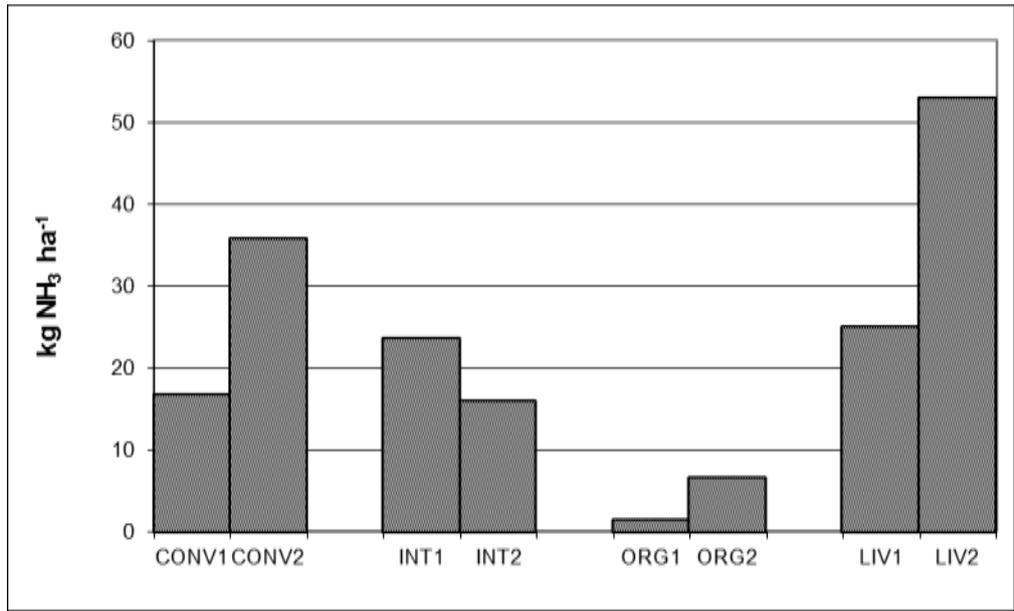


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1099 Figure 7 – Net Energy (NE) and Energy Use Efficiency (EUE).  
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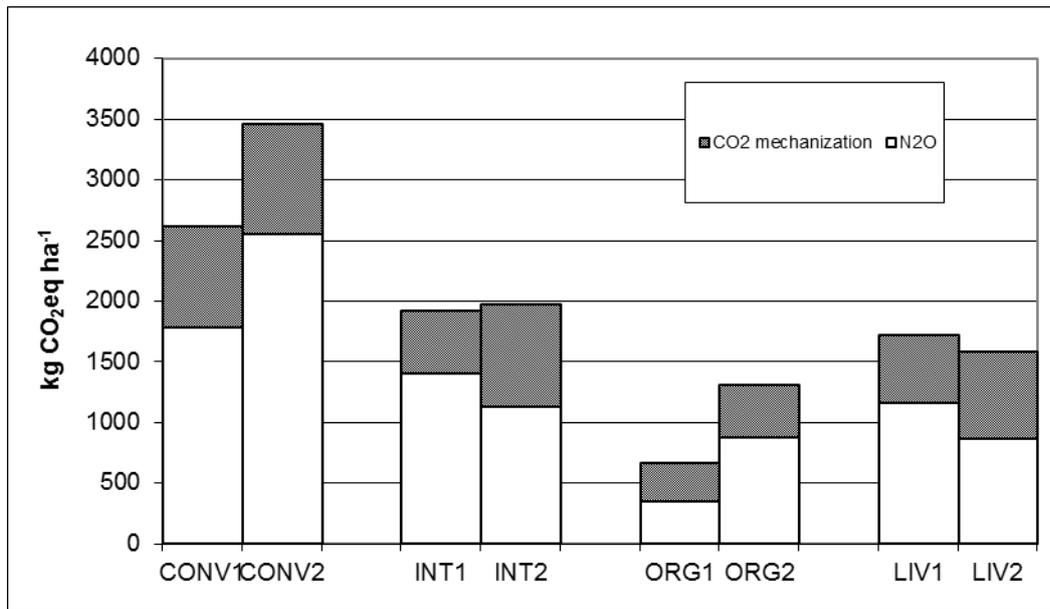


1101  
 1102  
 1103 Figure 8 – Ammonia emissions.  
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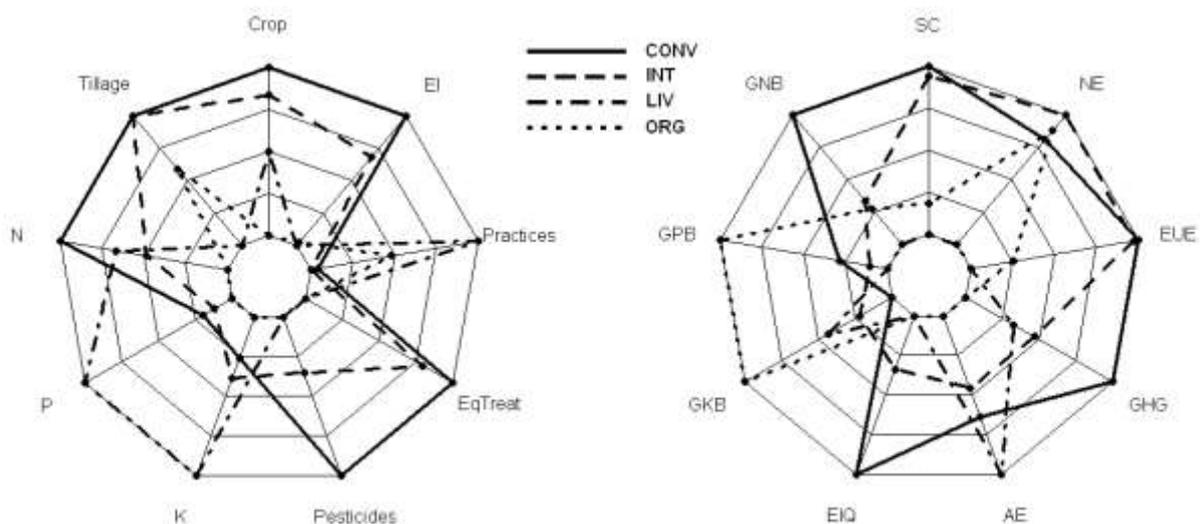
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1108 Figure 9 – Greenhouse gases emissions.  
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1110  
 1111  
 1112 Figure 10 – Radar graphs representing driving force indicators (left) and pressure indicators  
 1113 (right).

1114 List of abbreviation - Crop: Number of Crop; EI: Energy Input; Practices: Number of  
 1115 Practices; EqTreat: Equivalent Treatment; Pesticides: Consumption of Pesticides; K: K  
 1116 fertilisers; P: P fertilisers; N: N fertilisers; Tillage: Tillage Practices; SC: Soil Cover ; NE: Net  
 1117 Energy; EUE: Energy Use Efficiency; GHG: GHG emission; AE: Ammonia Emission; EIQ:  
 1118 Environmental Impact Quotient; GKB: Gross K Balance; GPB: Gross P Balance; GNB: Gross  
 1119 N Balance.



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