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

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Abstract

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

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

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

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

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

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

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

1 Introduction

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

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

Cropping system intensity is defined by European, national, and regional level regulations. This paper considers only the agronomic aspects, contained in the different regulations and do not consider the different ethical aspects that have led to them. Conventional cropping systems must satisfy statutory management requirements defined in the cross compliance system (73/2009/EC (EC, 2009a)), which represent the minimum legal limits. In Italy, the regional Rural Development Program (RDP) determines regulations for integrated farming systems, whereas organic agriculture is governed by European regulations 834/2007/EC (EC, 2007) and 889/2008/EC (EC, 2008). Among low-input cropping systems, integrated agriculture has been promoted for its reduced environmental impact and increased sustainable resource use (Alluvione et al., 2011; Morris and Winter, 1999). Organic farming has also been advocated as more sustainable than conventional systems over the long-term (Pimentel et al., 2005), as it uses the fewest inputs and therefore, is the least intense. Banned chemical products, improved nutrient recycling, and "minimisation of the use of non-renewable resources and off-farm inputs" are keys to its sustainability (Regulation 834/2007/EC (EC, 2007)).

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

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

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

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

This work analyses different cropping systems at various intensification levels (conventional, integrated, and organic) using an agro-environmental indicator set built of different indicators derived from literature. The investigation aims to grade these cropping systems on both input level and environmental pressures; thereafter, the results will be compared to the expected grade derived from the intensification levels as defined by regulation.

2 Materials and methods

2.1 Description of the area

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

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

2.2 Farm types

Conventional, integrated, and organic cropping systems of farms were considered in this study. Organic farms were further divided into arable organic farms and livestock organic farms according to their external input levels, which created four different farm intensification groups:

- conventional arable farms (CONV)
- integrated arable farms (INT)
- organic arable farms (ORG)
- organic livestock farms (LIV)

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

2.2.1 Farm survey and data collection

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

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

2.2.2 Farm descriptions

Table 1 reports a general description of the farms. The average UAA was 48 ha. The two organic arable farms were the smallest at 19 and 24 ha, while the other farms were more variable. Soil textures were loam or silt-loam; other soil characteristics varied more. Organic matter content was higher in livestock organic farms, followed by arable organic farms. The other arable farms were the lowest, except for one conventional farm that had a previous presence of permanent grassland. Total N content nearly tracked the organic matter trend as C/N ratio did not show a large variability. Olsen P levels were high in all the farms, and homogeneous among the groups. Exchangeable K was usually low.

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

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

2.3 Application of agro-environmental indicators

The selected farms were analysed using the set of 22 indicators derived from literature and reported in Figure 1. Those selected, according to the DPSIR schema (Kristensen, 2004; EEA, 2005), can be classified as driving force or pressure indicators. Driving force indicators represent system inputs related to land use planning, agricultural managements, chemical, and energy; pressure indicators represent the result of these practices and are usually not directly modifiable by farmers. Oenema et al. (2011) considers the AEI “soil cover” indicator a driving force indicator, however, we considered it a pressure indicator to recognize that farmers actively select the number and type of crops to grow based on economic strategies rather than on simply covering the soil for longer.

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

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

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

The majority of indicators represented system inputs (driving force indicators) or system impacts (pressure indicators), and therefore, results were generally considered to have lower sustainability when their values were high. However, *Number of Crops*, *Number of Practices*, *Soil Cover*, *Gross nutrient balances*, *Net Energy*, and *Energy Use Efficiency* have different interpretations, which have been detailed in the specific section.

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

2.3.1 Driving force indicators

2.3.1.1 Land use

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

2.3.1.2 Fertiliser use

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

2.3.1.3 Pesticides use

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

2.3.1.4 Energy use

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

All energy inputs, both direct and indirect, were calculated through mass flow and determined by multiplying inputs by the equivalent energy shown in Table 3, that represents the energy embedded in each product. The value for fertiliser energy input was computed by multiplying various N forms, P, and K quantities by their specific energy equivalent, and then the product-specific Formulation Packaging Transport coefficient (FPT) was added. Manure has no energy equivalent because it is a livestock farming by-product. Pesticide energy input was determined by multiplying the quantity of each active ingredient by its specific energy equivalent (Green, 1987), and then adding the pesticide FPT coefficient. Average herbicide, fungicide, and insecticide energy values were employed when necessary. Seed energy equivalents included the energy required for selecting, packaging, and transporting the seeds. Fuel energy input values were based on farmer reported diesel consumption; total lubricant energy (direct + indirect) and machine-embedded energy were considered to be proportional to diesel consumption. Table 4 lists the maximum and minimum values for each practice.

2.3.2 Pressure indicators

2.3.2.1 Land use

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

2.3.2.2 Fertiliser use

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

The gross nutrient balances were calculated as:

GNB, GPB and GKB = Fc + Fo + Ad + Bfx + Se - Off

where *Fc* was the mineral fertiliser nutrient supply, *Fo* was the organic fertiliser nutrient supply, *Ad* was the N and P atmospheric depositions, *Bfx* was the biological nitrogen fixation by legumes, *Se* was the seeds nutrient content, and *Off* was the crop nutrient off-take. The values utilised for nutrient content both in crops and seeds are shown in Table 5. The values used for atmospheric deposition were 26 kg N ha^{-1} y^{-1} (Bassanino et al., 2011) and 1.8 kg P ha^{-1} y^{-1} (study area value, Experimental Centre, University of Turin). The legume fixation value was calculated as:

Bfx = Off – (Fc + Fo + Ad + Se)

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

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

2.3.2.3 Pesticide use

The two indicators in the pesticides use pressure group are *Load Index* and *Environmental Impact Quotient*. The *Load Index* (LI) (Bechini and Castoldi, 2009; OECD, 2004) indicates potential effect on a non-target organism class. It is calculated by dividing the application rate by the LD50 or the LC50 of each active ingredient. The *Environmental Impact Quotient* (EIQ) value (Kovach et al., 1992) is more complex to calculate as it takes into account active ingredient properties and analyses the potential impact on three different components: farmers, consumers, and environment. The present work used the active ingredient properties defined by the Pesticide Property Database (University of Hertfordshire, 2012) and the Italian Ministry of Agriculture database (MIPAAF, 2012).

2.3.2.4 Energy use

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

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

2.3.2.5 Gaseous emissions

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

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

The Tier 2 methodology for organic fertiliser addresses three different NH_3 loss phases: housing, storage, and spreading. As this paper focuses on only cropping systems, ammonia emissions during housing and storage were not considered. The amount of nitrogen available for spreading was calculated as N excreted minus N lost during housing and storage. N losses during housing and storage were calculated by the EMEP methodology, while N_2O losses during manure storage were calculated using the IPCC methodology (IPCC 2006), adjusted with a localized EF value of 0.02 for cattle solid manure (ISPRA, 2011).

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

GHG Emissions were calculated per the IPCC methodology (IPCC 2006) and expressed as CO_2 equivalents. According to the methodology and without a change in land use, the emissions considered were those from diesel consumption and from direct and indirect N_2O losses from agricultural soils. Diesel fuel combustion accounts for CO_2, $CH_{4,}$, and N_2O emissions. To calculate those emissions, a diesel density of 0.855 kg l^{-1} was used (Bosch, 1996).

Direct N_2O losses consider all the nitrogen added to the system as fertiliser and as crop residues. A Tier 1 approach was applied because of a lack of specific emission factors. Indirect N_2O losses were calculated with Tier 2, applying EMEP/EEA methodologies for NH_3 and NO losses.

2.4 Data analysis

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

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

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

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

3 Results

3.1 Driving force indicators

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

Table 7 represents the ability of each indicator to correctly grade the different cropping systems through the Kendall τ(b) correlation test.

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

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

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

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

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

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

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

3.2 Pressure indicators

3.2.1 Land use

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

3.2.2 Fertiliser use

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

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

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

3.2.3 Pesticide use

Load Index graded correctly CONV and INT (Figure 5) for each class of non-target organism (algae Kendall τ(b) -0.95, P(τ) 0.004, fishes Kendall τ(b) -0.76, P(τ) 0.021, bees Kendall τ(b) -0.86, P(τ) 0.009, earthworms Kendall τ(b) -0.76, P(τ) 0.021, mammals Kendall τ(b) -0.86, P(τ) 0.009, birds Kendall τ(b) -0.95, P(τ) 0.004). *Load Index* trended in a like pattern on all farms for each class of non-target organism. The values were lower for birds and mammals, while the highest values were for fishes and algae. The *Environmental Impact Quotient* (EIQ) differentiated the cropping systems better, and it made evident a lower potential impact of pesticide use in INT than in CONV (Figure 6) (Kendall τ(b) -0.95, P(τ) 0.004). Analysis of the three *EIQ* components (farmers, consumers and environment) trended like total *EIQ*. INT had the lowest impact values in each. The environmental component was the most impacted; consumers were impacted the least.

3.2.4 Energy use

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

3.2.5 Gaseous emissions

In arable cropping systems, the *Ammonia Emissions* (Figure 8) indicator trended similarly to nitrogen fertiliser inputs; that is, values decreased from CONV through INT to ORG. LIV showed the highest values. Kendall correlation was not significant. Figure 9 displays *GHG Emissions* as the sum of two sources, expressed in CO_2 equivalent. The total *GHG Emissions* presented values that distinguished between cropping system groups. The highest values were in CONV; INT and LIV had similar intermediate values, and the lowest values were those calculated for ORG (Kendall τ(b) -0.62, P(τ) 0.041). N_2O emissions trended like the total *GHG emissions*.

4 Discussion

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

4.1 Land Use

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

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

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

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

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

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

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

4.2 Fertilisers use

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

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

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

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

Therefore, in terms of N fertiliser inputs, the farms decreased in intensity from conventional to integrated to arable organic systems. Livestock organic cropping systems demonstrated an input level similar to integrated cropping systems. Conventional and integrated system differences related to fertiliser use limits defined by the RDP for integrated cropping systems. If the analysis had considered all N additions, including N from legume fixation, the trend would be altered to show the highest values for conventional and livestock organic systems, and the lowest values for integrated and arable organic systems.

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

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

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

4.3 Pesticide use

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

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

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

4.4 Energy use

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

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

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

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

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

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

4.5 Gaseous emissions

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

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

4.6 Radar

Radar graphs described and made evident the impact of the different cropping systems (Bockstaller et al., 1997; Sattler et al., 2010). They made it easy to understand how driving forces and their consequent pressures determine the grade of the different systems. Figure 10 shows two radar graphs, one for driving force indicators and one for pressure indicators. The indicator *Irrigation* varied highly among and within the cropping system groups because of differing pedological and climatic conditions; at the same time, it is unaffected by the different intensification levels. As it was unable to differentiate farms based on their intensity levels, it was excluded from the graph. Among pressure indicators, *Load Index* values were not represented as *Environmental Impact Quotient* better graded the different farms.

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

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

The agro-environmental indicator set analyses underlined two main correlated factors, which allowed differentiation of intensification levels among the cropping systems. First, legal input limits and management practices do reflect on intensification levels. Second, organic production regulations that defined management practices, in particular the presence of meadows and use of organic fertilisers, do influence those systems, and could similarly influence the environmental performance of other cropping systems if practiced. This potential calls for evaluation on how to improve regulations to increase system sustainability.

The goal to design and develop usable tools to assess the environmental impact of agricultural policy has grown in recent years. Improvements in agro-environmental policy evaluation standards, direct support schemes, and recommendations from the Common Monitoring and Evaluation Framework of the European Commission, which requires Member States to assess the impacts of their RDP (Schuh et al., 2011), have converged to focus on the same goal. Member States often use routine administrative data to monitor the effectiveness of agro-environmental measures, but this often does not reliably measure the environmental impacts of the policy. Adoption of agro-environmental measures does not guarantee that environmental standards will be attained (Mauchline et al., 2012).

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

5 Conclusion

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

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

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Tables

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

	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 $100g^{-1}$)	0.15	0.21	0.15	0.15	0.24	0.08	0.15	0.09

Table 2 – Crop DM yield (t ha^{-1}) of the eight farms studied.

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)[a]		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		

[a] second crop

Table 3 – Coefficients used to calculate Energy Input, Net Energy and Energy Use Efficiency. Energy equivalent represents the energy embedded in each input/output product.

Input/Output		U.M.	Energy equivalent
Crop	**Product**		
Maize	grain [a]		18.92
	silage [b]		17.9
	straw [a]		18.67
	seed [b]		113.2
Wheat	grain [a]		18.42
	straw [a]		18.17
	seed [b]		31.3
Lucerne	hay [c]		18.84
	seed [d]		31.4
Soybean	grain [a]		23.65
	seed [b]		40.6
Meadow	hay [b]		17.6
	seed [d]	MJ kg^{-1} DM	31.3
Barley	grain [b]		18.4
	straw [b]		16.8
	seed [b]		31.4
Switchgrass	hay [d]		17.2
	seed [d]		31.3
Bean	grain [d]		16.74
	seed [d]		40.6
Italian ryegrass	hay [b]		17.2
	seed [b]		31.3
Sorghum	silage [d]		18
	seed [d]		31.4
Grassland	hay [b]		17.6
Tomato	fruit [e]	MJ kg^{-1} FM	1.3
	seedling [f]	MJ $plant^{-1}$	0.28
Fertiliser			
N- NH_4 [b,g]			39
N-ureic [b,g]			48
N-NO_3 [b,g]			32
N-other [h]			50
P_2O_5 [b,g]			4
K_2O [b,g]		MJ kg^{-1}	5
FPT[h] for N fertilisers [i]			1.5
FPT[h] for P fertilisers [i]			9.8
FPT[h] for K fertilisers [i]			7.3
FPT[h] for NP fertilisers [i]			5.7
FPT[h] for other fertilisers [i]			6
Pesticide			
Herbicides [a]			264
Fungicides [a]			168
Insecticides [a]		MJ kg^{-1} a.i.	214
Formulation [a]			20
Packaging [a]			2
Transport [a]		MJ kg^{-1}	1.3
Other			
Diesel [a]		MJ l^{-1}	46.9
Lubricants [h]		MJ l^{-1} diesel	3.6
Machinery energy embedded			12

[a] Alluvione et al., 2011
[b] Bechini and Castoldi, 2009
[c] Fluck, 1992
[d] Estimated
[e] Meul et al., 2007
[f] Canakci et al., 2005
[g] Kongshaug, 1998
[h] Dalgaard et al., 2001
[i] Castoldi and Bechini, 2006

[h] FPT = Formulation, Packaging and Transportation

Table 4 – Diesel consumption for the different farm practices.

Operation	$l\ ha^{-1}$ (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

Table 5 – Coefficients used to calculate the nutrient balance crop off-take.

Crop	Product	N (%DM)	P (%DM)	K (%DM)
Maize	grain [a]	1.70	0.35	0.67
	silage [a]	1.20	0.22	1.00
	straw [a]	0.70	0.13	1.50
Wheat	grain [a]	2.30	0.39	0.50
	straw [a]	0.60	0.09	1.25
Lucerne	hay [a]	2.80	0.31	1.83
Soybean	grain [a]	6.70	0.74	2.25
Meadow	hay [a]	2.20	0.35	2.58
Barley	grain [a]	2.00	0.35	0.83
	straw [a]	0.60	0.09	1.08
Switchgrass	hay [b]	1.50	0.35	2.25
Bean	grain [a]	6.20	0.96	3.42
Italian ryegrass	hay [a]	1.50	0.35	2.25
Sorghum	silage [a]	0.90	0.13	0.83
	grain [a]	1.80	0.52	1.33
Grassland	hay [a]	2.20	0.35	2.08
Tomato	fruit [b]	2.50	0.18	4.83
Generic seeds [c]		1[d]	1[d]	3[d]

[a] Grignani et al., 2003

[b] Estimated

[c] Nielsen and Kristensen, 2005; Schröder et al., 1996

[d] $kg\ ha^{-1}$

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

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^{-1})	771	1180	694	473	0	0	0	0
	Organic fertilisation (kg ha^{-1})	0	0	0	0	1977	8710	25163	33524
	N fertilisation (kg ha^{-1})	222.7	310.4	163.4	123.1	11.1	42.7	158.5	214.6
	P fertilisation (kg ha^{-1})	17.2	31.7	25.3	13.4	3.8	16.7	79.5	85.6
	K fertilisation (kg ha^{-1})	32.8	121.0	131.0	68.9	10.6	47.2	167.9	257.4
Pesticides use	Consumption of Pesticides (kg a.i. ha^{-1})	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^{-1})	30.6	40.2	25.5	31.9	9.4	20.0	13.1	15.3

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

Indicator group	Indicators	Kendall's tau_b	Sig.
Driving force indicators			
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
Pressure indicators			
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

Figures

Figure 1 – Relationships between driving force indicators and pressure indicators. The symbol reported for each indicator specifies the optimal value of the indicator: “+” sustainability is higher when the indicator is high; “–” sustainability is higher when the indicator is low; “0” sustainability is higher when the indicator is zero.

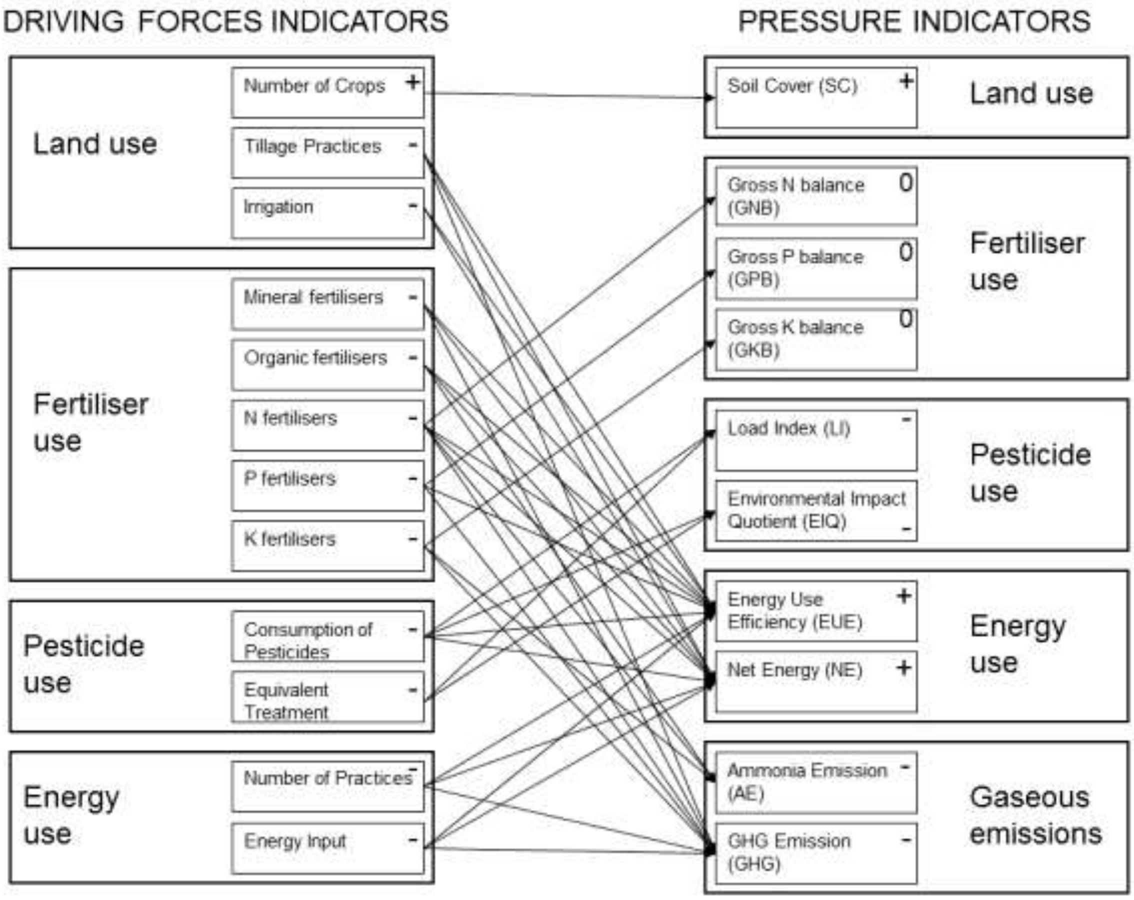

Figure 2 – Energy Inputs.

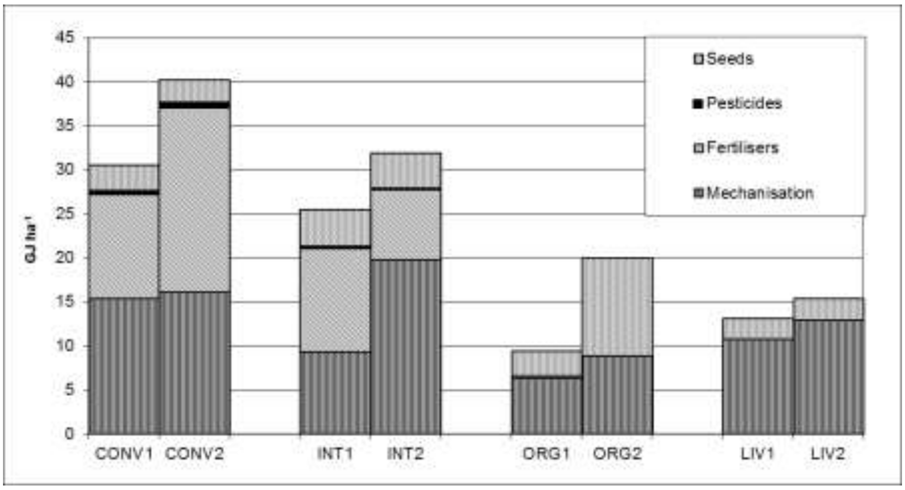

Figure 3 – Percentage of the year with soil cover.

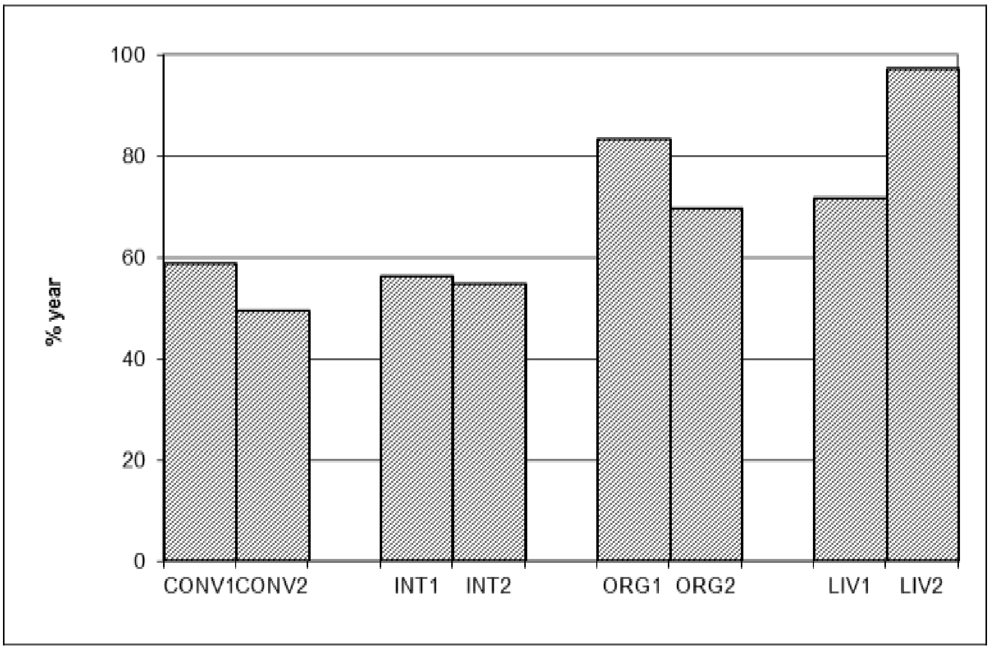

Figure 4 – N, P, and K inputs (left) and gross nutrient balance (right).

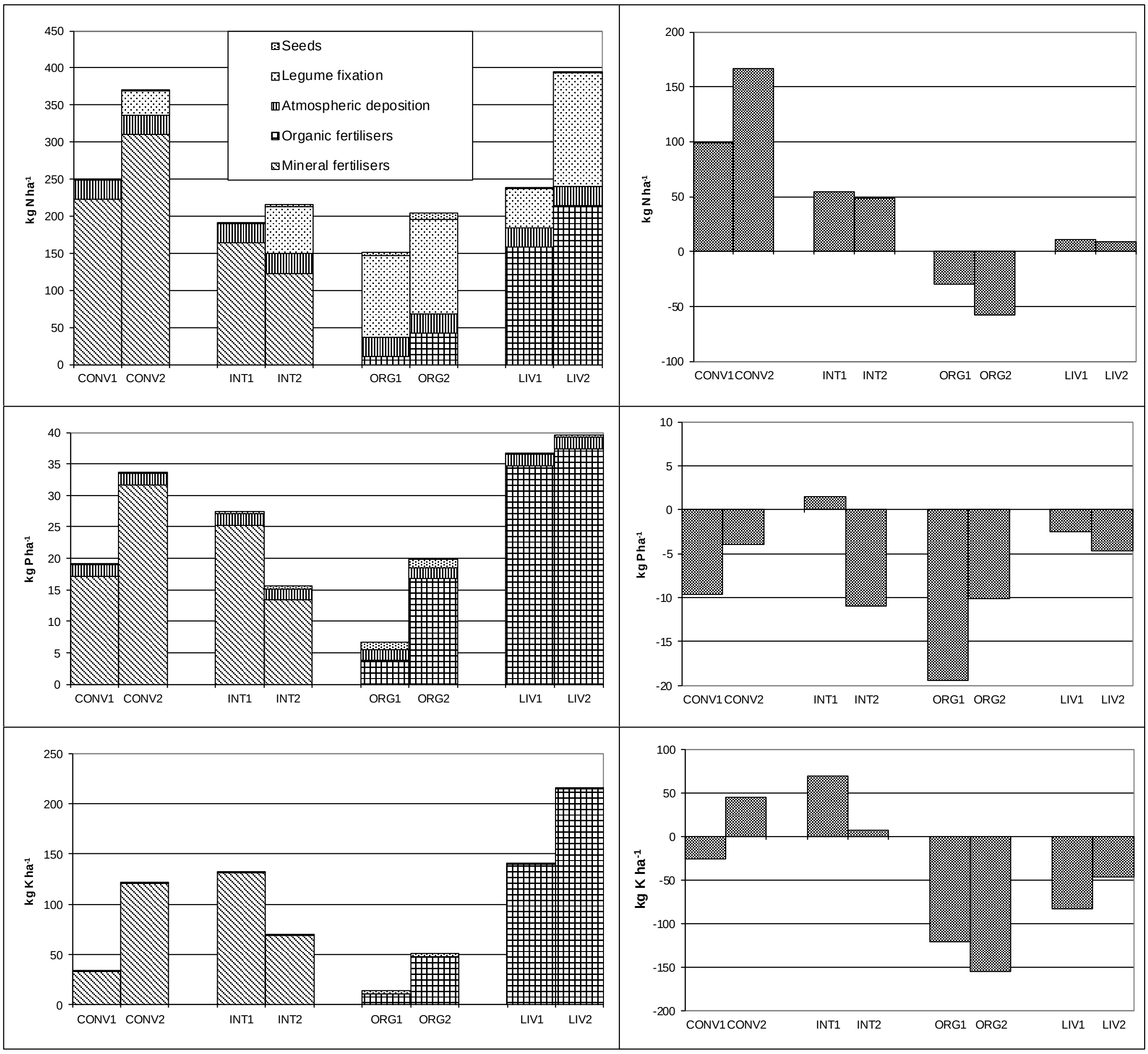

Figure 5 – Load Index for different non-target organisms.

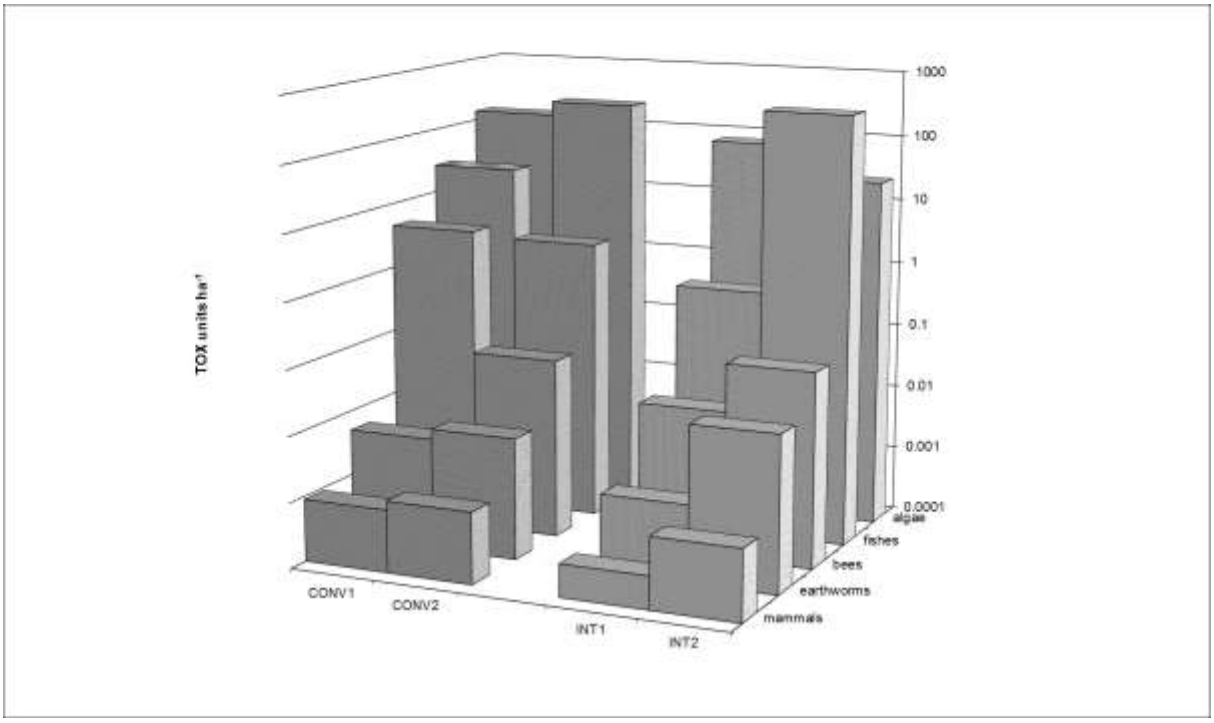

Figure 6 – Different components of Environmental Impact Quotient (EIQ).

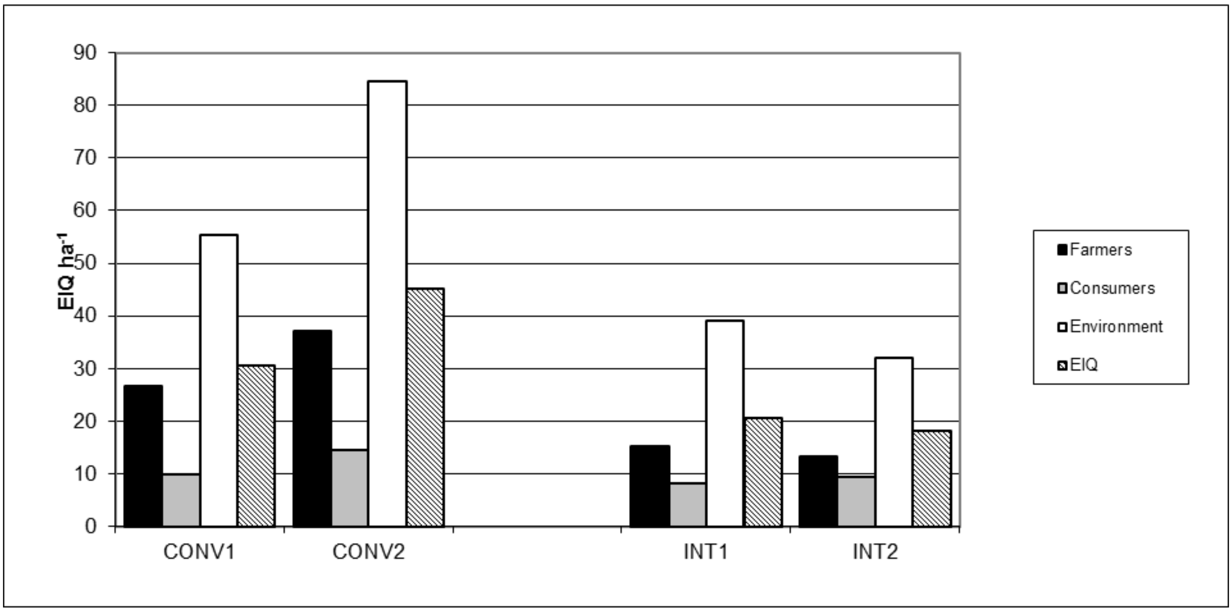

Figure 7 – Net Energy (NE) and Energy Use Efficiency (EUE).

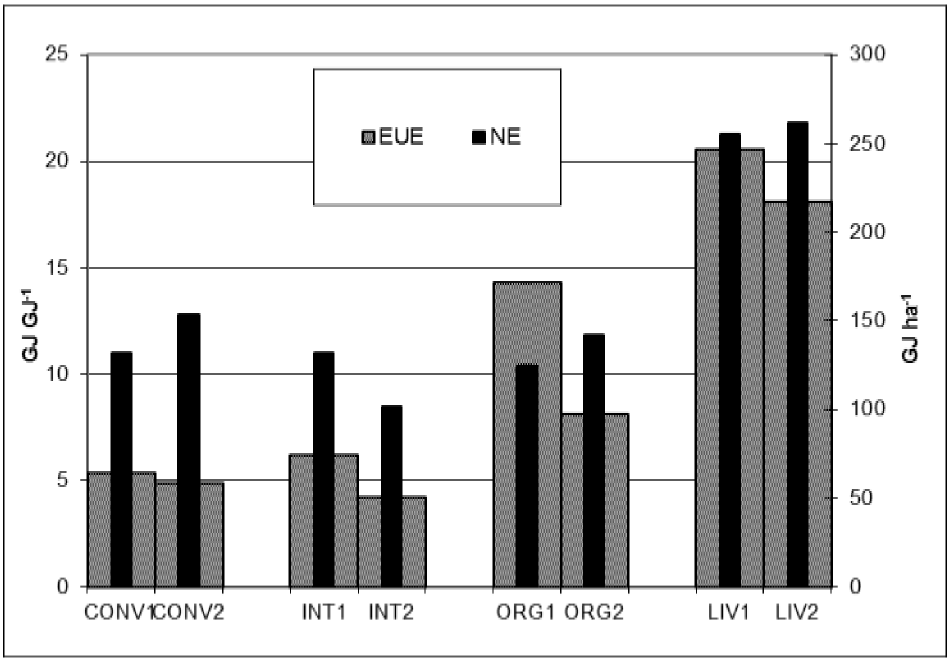

Figure 8 – Ammonia emissions.

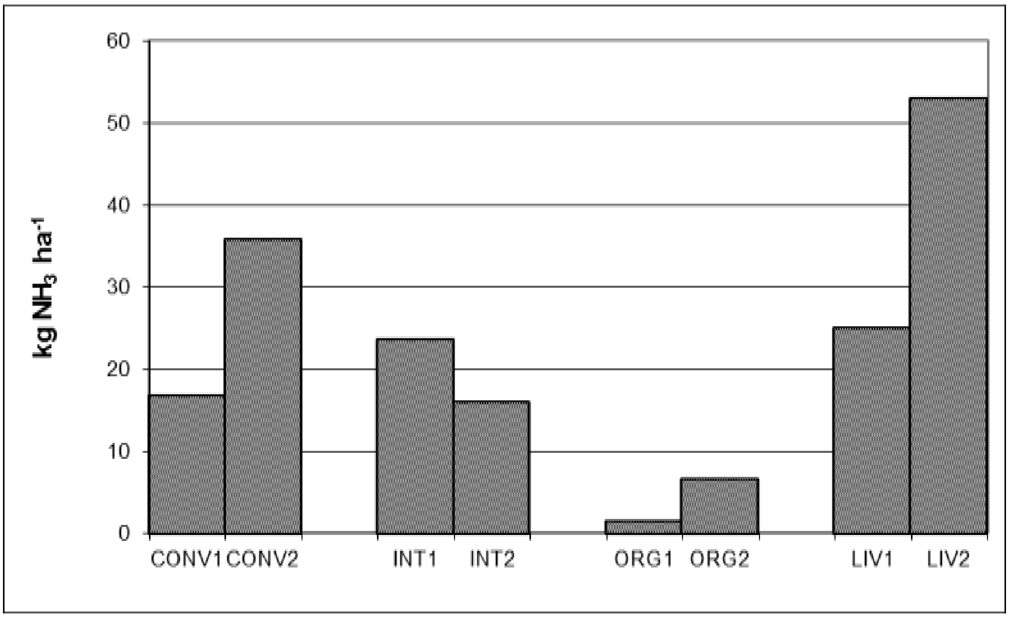

Figure 9 – Greenhouse gases emissions.

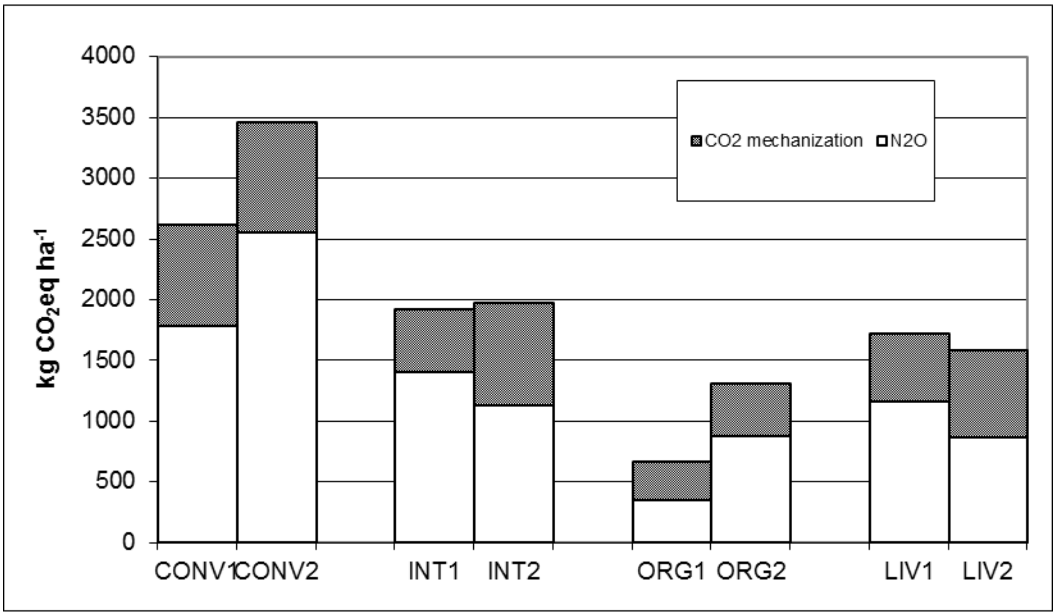

Figure 10 – Radar graphs representing driving force indicators (left) and pressure indicators (right).

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