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INTEGRATED AND SUSTAINABLE MANAGEMENT OF INTENSIVE BROILER FARMING ACCORDING TO THE ENVIRONMENTAL BALANCE LOGIC

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ABSTRACT

INTEGRATED AND SUSTAINABLE MANAGEMENT OF INTENSIVE BROILER FARMING ACCORDING TO THE ENVIRONMENTAL BALANCE LOGIC

With respect to meat production in Italy, poultry meat production is among the main ones with a production of 1.25 million tonnes, 68% of which is broiler meat (Avec, 2015). Most of the broiler meat come from standard indoor system farms and they are located in the North-East regions (Unaitalia, 2014), often concentrated in specific areas, that frequently leads to criticism due to emissions, in particular ammonia (NH_3), nitrous oxide (N_2O) and methane (CH_4) produced and the difficulty to obtain a proper disposal of poultry manure. This is because the broiler farms in these areas are a lot and all are characterized by the absence of field where the poultry manure could be spread. The broiler standard indoor system is characterized by a standard production chain, which starts with the companies that produce the feed and closes with the companies that slaughter and prepare the finished product. However, the poultry chain has never given much importance to the co-product that inevitably forms, that is, the poultry manure. The poultry manure is a co-product, it has an excellent amounts of nitrogen and phosphorus (Chamblee and Todd, 2002). This situation leads to problems of the emissions of broiler farm and the correct management of the poultry manure and the consequent environmental impacts. For these reasons, the research follows three research lines: i) use mix of microorganisms (LW) in the broiler breeder phase (PM = poultry manure treatment, DW = drinking water treatment and CL = control or no treatments); ii) three utilization scenarios of poultry manure (direct field spread = DFS, production of organic fertilizers = POF and combustion plant = CP). The last two scenarios produce organic fertilizer, also (IFA,

2012); iii) application of a field simulation model and compare cultures with high (Hi) and low (Li) input, in particular respect nitrogen (N). The third line of research has been developed because, although not strictly related to the use of poultry manure, it concerns nitrogen (N) and its application to a crop. Since the poultry manure has a lot of nitrogen (N), it has been considered interesting to evaluate this element, considering the problems connected to it also and especially bound by the Nitrates Directive (91/676/CEE and DM 5046 of 25 February 2016). The first line, was evaluated using the methodology Life Cycle Assessment (LCA). The second with LCA and DeNitrification-DeComposition (DNDC) model approaches. Finally, the last with DNDC model.

From the first line of research (i), it can be deduced that, except the greater environmental impact of feed that are 81% of CL, 79% of PM and DW, microorganism treatments have reduced emissions from broiler breeding farm and hence, environmental impacts. The environmental impacts of the two types of treatment (PM and DW) are compared to the CL both. The Terrestrial Acidification (TA) expressed as kg SO_2 eq., in PM is less than 11.057% and in DW is 4.876%. In the Particular Matter Formation (PMF) expressed as kg PM_{10} eq., in PM is less than 9.076 and in DW is less than 2.727. In the Eutrophication Potential (EP) expressed as kg PO_4 eq., in the DW is less than 5.212 and in DW is less than 0.101. On the other hand, there have not been significant results with a lower environmental impact as regards the Climate Change (CC) expressed as kg CO_2 eq. Finally, with regard to housing emissions, especially with respect to NH_3, Monte Carlo analysis showed a significant reduction in emissions between the different scenarios. In PM there were less emissions of 69% and 77% in DW, respectively compared to CL.

Instead, from the second line of the research (ii), the environmental impacts of utilization scenarios of poultry manure (POF and CP) are both compared to the DFS. In Eutrophication (EP) expressed as kg PO_4^- eq., there is a lower environmental impact of 33% in the CP. Instead, it is higher of 16.2% in the POF, in agreement with other studies, also (González-García et al., 2014). Another important impact category to consider is the Acidification (AP) expressed as kg SO_2 eq., that is higher in POF scenario of 2.5%, insteed it is less of 9.7% in CP. This becouse the N leach (nitrate), is 22.11, 20.17 and 16.43 kg N/ha/y in a time horizon of 100 years in production of POF, DFS and CP, respectivelly. The Photochemical Oxidation expressed as kg C_2H_4 eq., it is less of 5.2% in the POF and it is less of 28% in the CP. The Particular Matter Formation (PMF) expressed as PM_{10} eq., it is less of 18% in the CP. The Abiotic Depletion of Fossil Fuel (FD) expressed as MJ, it is less of 9.5% in the CP and insteed, it is higher of 5,4% in the POF. The Cumulative Energy Demand (CED) expressed as MJ, it is less of 8.1% in the POF and it is less of 4.9% in the CP. Regarding FD, and especially for the CED, values of higher environmental impact for POF, it is due to the high energy request.

Finally, from the thrid line of the research (iii), despite of its positive applications, the use of active light crop canopy remote sensors for in-season site-specific nitrogen (N) management, has some drawbacks. The development of algorithms to estimate in-season N rates is based on data that relates canopy spectral data to potential yield and N uptake over multiple years and locations. Furthermore, canopy sensing-based N rate algorithms use in-season estimation of canopy N status to prescribe N rate need to reach yield potential, but is does not account for crop streses between sensing and harvest. The goal of this third study was to develop and test a methodology for combining normalized difference vegetation index data (NDVI) and simulating the assess spatial variability of corn N stress and in-season N rate. Using two season data (2008-2009) of five corn fields located in the Venice lagoon watershed, spatial model calibration and simulation were conducted using the CERES – Maize model in DSSAT in conjunction with the GeoSpatial Simulaton (GeoSim) tool in the Quantum GIS software. The model was first optimized to properly predict the yield, and subsequently to match the simulated and the NDVI-derived leaf area index (LAI). Model accuracy in yield estimation was reached by soil parameters optimization and was not

negatively influenced by model optimization for LAI. In order to evaluate the advantages of coupling modelling and spectral data, N stress was simulated and optimum rates able to minimize it were evaluated. The incorporation of proximal sensed-derived data into the model guaranteed to increase the accuracy of Nitrogen stress simulation, due to the relationship between NDVI, LAI and N stress. Manage an inseason site-specific fertilization aiming to minimize N stress could N efficiency not guarantee to satisfy other criteria, such as the maximum achievable yield, the economic convenience or the environmental impact of the fertilization.

ACKNOWLEDGMENTS

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CHAPTER I

INTRODUCTION

1.1 Poultry production in Europe and Italy

The environmental impact of livestock production has been increasing in recent years (Steinfeld et al., 2006). The livestock sector is increasingly involved in the use of resources such as land, water and energy, and has a significant impact on air, water and soil due to its emissions. For example, according to the World Food and Agriculture Organization (FAO, 2006), the worldwide livestock sector accounts for 18% of global greenhouse gas emissions. This contribution is due to carbon dioxide (CO_2) emissions from fossil fuels used for production, emissions from manure and enteric fermentation of ruminants, and emission of nitrous oxide (N_2O) fertilizer during cultivation (Steinfeld et al., 2006). This situation is even more relevant, assessing the density of animals in the European Union expressed as the number of livestock units per hectare of agricultural area used (Figure 1.1).

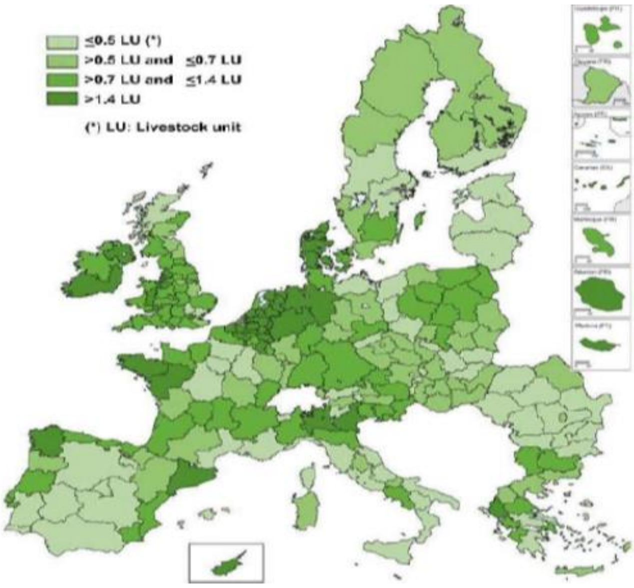
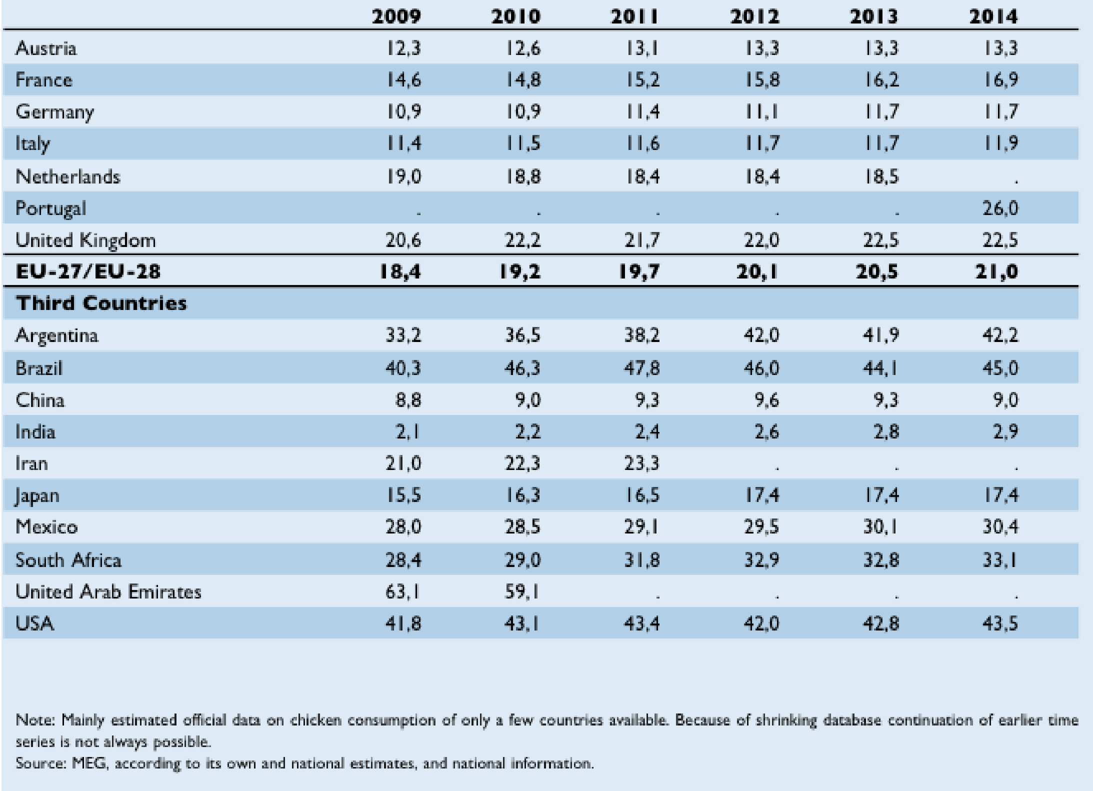


Figure 1.1: Density of animals in the European Union expressed as the number of livestock units per hectare of agricultural area used (EUROSTAT 2009).

In addition to changes in production practices, eating less meat or reducing wastewater production, it is often seen as a possible solution to reduce the environmental impact of breeding (Carlsson-

Kanyama, 1998, Pimentel and Pimentel, 2003, Reijnders and Soret, 2003; Baroni et al., 2007). In fact, a balanced plant-based diet can provide all nutrients needed for healthy living (Appleby et al., 1999). However, eating meat is not only a reflection of nutritional needs, but is also determined by taste, smell and texture, as well as geography, culture, ethics and wealth (Richardson et al., 1993). In OECD member countries, more than one quarter of the energy content of an average diet is still based on animal products (FAOSTAT, 2009). Moreover, more people in developing countries eat meat (FAO, 2002). Then, choosing a more environmentally-friendly breeding, alongside a proper diet, can therefore reduce the environmental impact. For example, to choose between different types of meat or between protein from meat or eggs, we need a consistent assessment of their environmental impact. In particular, the livestock sector that in the last years has continued to grow, is that of chickens. Consequently, more attention is being paid to this type of breeding. The poultry meat has seen an increase worldwide. In 1958, global poultry meat production was around 15 million tons, in 2013 it got almost 109.3 million tons (Avec, 2015). Poultry meat production have alternation of production following the correlation between meat consumption and health problems, such as obesity and cancer (Schonfeldt and Gibson, 2008). In addition, some diseases led negative effects on the market such as avian flu. However, the poultry meat production has been following an upward trend following several favorable points in this sector. These favorable points are considered a functional food of poultry meat, which poultry meat has a light-colored flesh and good nutritional status (Petracci et al., 2014). The poultry meat has a high content of proteins (20-23%), of polyunsaturated fatty acids (PUFA), of iron and B12 vitamin, of a low lipid content (1.2% in the chest and 3.8% in the thigh), cholesterol (60-80 mg/100g of meat) and sodium (Hernandez and Gondret, 2006; Petracci C., 2009; USDA, 2008). Another favorable point of the poultry sector, it is the absence of religious and ethnic prejudices. The species gallus gallus is the largest of these variants with a 20% of the total of poultry products and production of chicken broilers are higher. Hence, the poultry products are the most produced and consumed worldwide, after swine meat. In

2022, the researchers assumed that the poultry meat will be 46% of the meat consumed worldwide. The poultry associations supported this poultry sector word record also (Unaitalia, 2014). The largest producers of poultry meat, according to data (Avec, 2015), are USA with 19.7 million tons of meat (chicken 84%), China with 18 million tons (71% chicken), Brazil with 13.2 million tons (95% chicken) and EU with 12.7 milioni tons (77% chicken). In addition, demand continues to increase in the developing countries world. In 2015, the world's poultry production has reached 109.3 milioni tons, with an estimated value of chicken meat productions 91 milioni tons (AVEC, 2015). The researcher estimated an annual per capita consumption of chicken meat in the 2015 year, specially broiler to 19.8 kg in EU (Table 1.1).



	2009	2010	2011	2012	2013	2014
Austria	12,3	12,6	13,1	13,3	13,3	13,3
France	14,6	14,8	15,2	15,8	16,2	16,9
Germany	10,9	10,9	11,4	11,1	11,7	11,7
Italy	11,4	11,5	11,6	11,7	11,7	11,9
Netherlands	19,0	18,8	18,4	18,4	18,5	.
Portugal	.	.	.	.	.	26,0
United Kingdom	20,6	22,2	21,7	22,0	22,5	22,5
EU-27/EU-28	**18,4**	**19,2**	**19,7**	**20,1**	**20,5**	**21,0**
Third Countries						
Argentina	33,2	36,5	38,2	42,0	41,9	42,2
Brazil	40,3	46,3	47,8	46,0	44,1	45,0
China	8,8	9,0	9,3	9,6	9,3	9,0
India	2,1	2,2	2,4	2,6	2,8	2,9
Iran	21,0	22,3	23,3	.	.	.
Japan	15,5	16,3	16,5	17,4	17,4	17,4
Mexico	28,0	28,5	29,1	29,5	30,1	30,4
South Africa	28,4	29,0	31,8	32,9	32,8	33,1
United Arab Emirates	63,1	59,1	.	.	.	.
USA	41,8	43,1	43,4	42,0	42,8	43,5

Note: Mainly estimated official data on chicken consumption of only a few countries available. Because of shrinking database continuation of earlier time series is not always possible.
Source: MEG, according to its own and national estimates, and national information.

Table 1.1: Broiler meat consumption in selected EU and third countries (kg/head)

Italy is in fifth positions among the major producers of meat poultry in Europe, preceded by France, Germany, Poland and Spain followed by the Netherlands, Spain and the United Kingdom (Avec, 2015). The poultry meat production is around a million tons in Italy (1.258.000 tons) (Figure 1.2).

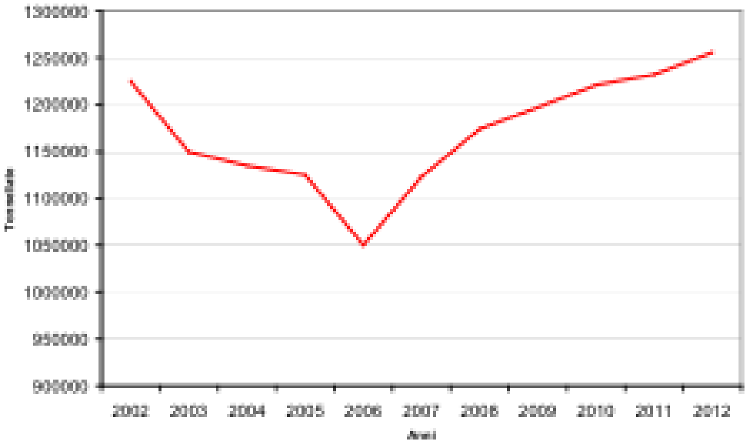


Figure 1.2: Performance of meat production poultry in Italy in the last decade (Avec, 2013).

In 2013, poultry production was divide in Italy (Unaitalia, 2014): 863.400 tons of chicken meat (broiler), 313.500 tons of turkey meat, 30.000 tons of laying meat, 51.100 tons of other poultry meat. In Italy, as in the rest of the world, the self-sufficiency level for poultry meat is positive. The 40% of Italian production poultry meat comes from the Veneto, where there are 12% of the 4.700 Italian poultry farms who they raise poultry meat (Cerolini, 2008). In this region there are 928 chicken farms for meat of which 49.5% is located in the province of Verona (Figure 1.3).

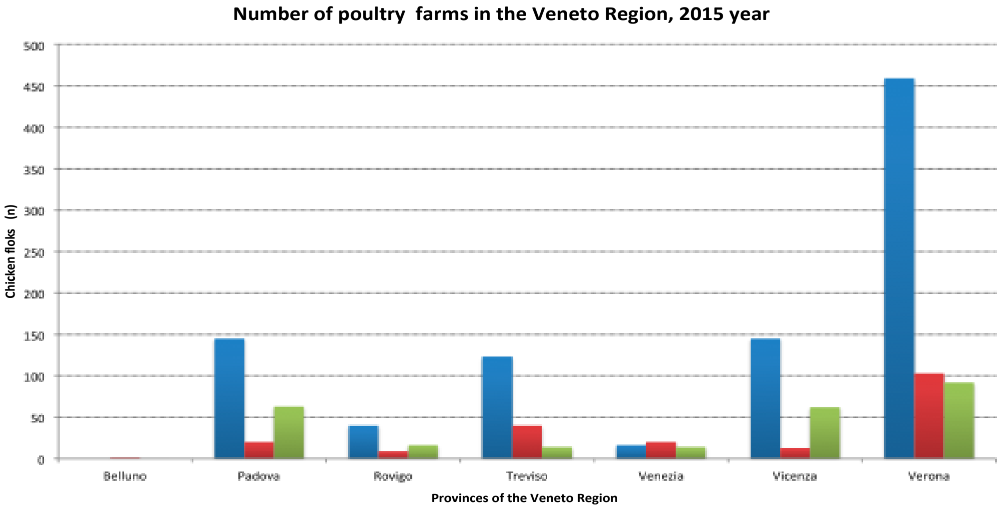
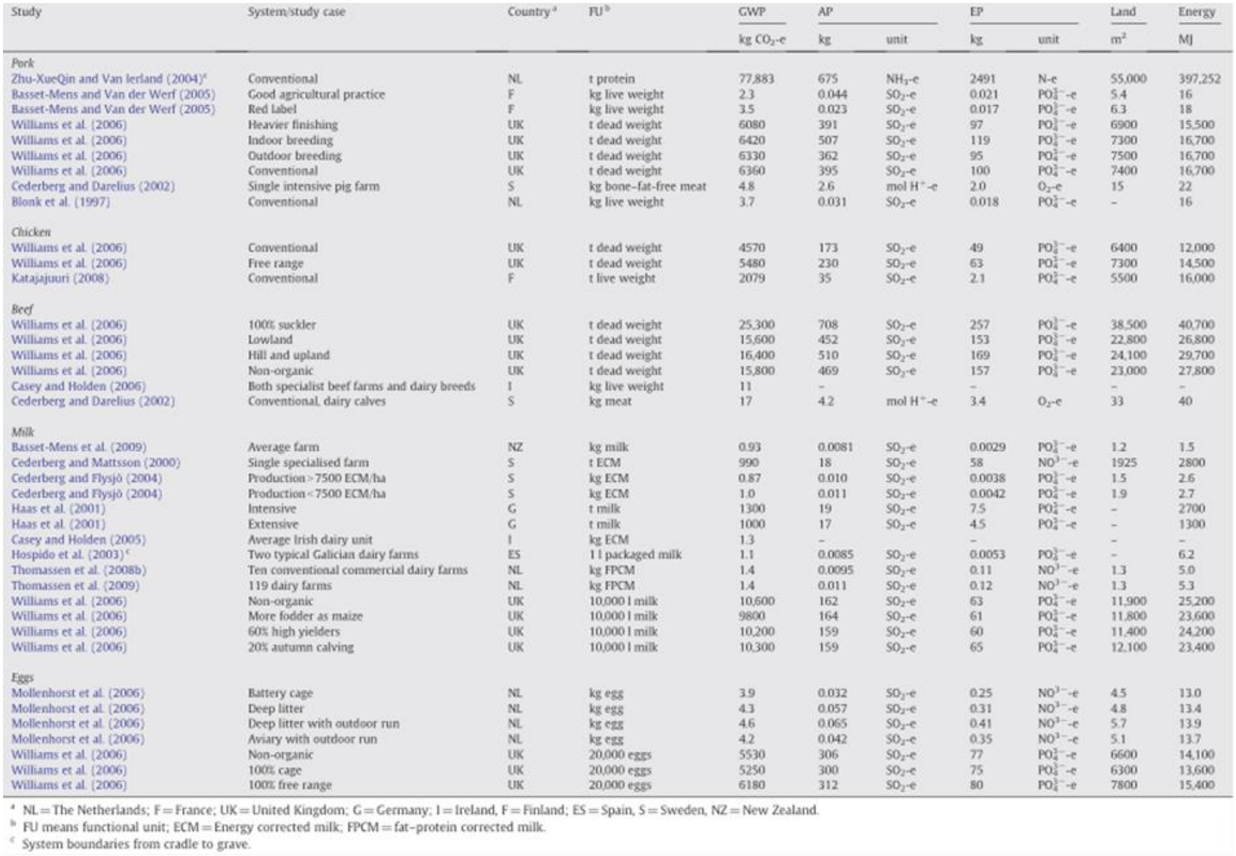


Figure 1.3: Poultry farms in the Veneto Region, SCS4, 2015.

Instead, regarding poultry farms in Friuli Venezia Giulia (FVG) region, there are 108 chicken farms and 52.345.581 heads (ISTAT, 2007), many of which broiler farms are located in the Udine province. The average size of poultry meat farms in these regions stood at values of about 52.000 birds. There are two farming systems in Italy and in these regions: intensive and semi-intensive. The difference is that the semi-intensive system, in addition to the indoor runs, has a wider area outside to be accessed by the animals at certain times of the cycle, when the enclosures are opened. Some studies have shown that the semi-intensive farming is more productive than the intensive, because the animal performance is better, with a more efficient feed conversion (Mark Aurelio Neves da Silva et al., 2003). However, the more kind of farming is the production of poultry meat addressed in an intensive production system in the regions Veneto and FVG. The intensive production system increases production and satisfies growing demand for chicken meat. Intensive farming uses in these regions, selected hybrid chicken, the genetic lines commonly used are ROSS and COBB (Cerolini, 2008; Aviagen, 2014; Cobb-Vantress, 2014). These hybrids chicken have influenced the duration life of chicken or production cycle. In 1950, chicken reached the live weight of 1.6 kg in 16 weeks with a feed conversion of 3.75, while the same weight today is achieved in 5 weeks with a feed conversion of 1.88 (Havenstein et al, 2003). Intensive farming is conducted in closed shelters, in which the farmer controlled microclimate, he can have high farming intensity (11-18 units/m^2) and high mechanization of operations. In Italy, currently 93% of the production of meat chickens is produced under an intensive system and a partial vertical integration of the supply chain (Fletcher, 2004). In the partial integration systems, the cycle of production stages take place under the integrant supervision, represented in the Italian reality from the animal feed manufacturer, except for production of broiler breeding (made by genetic international companies) and the rearing (carried out by the farmer). The farmer monitoring is linked to the integrant subject via an agistment contract in which the industrial company (integrant subject) provides the chicks, feed, technical assistance and health care, while the farmer (integrated part) provides structures and equipment for the animal, labor and costs such as water, electricity and gas. At the end of the production cycle, the integrant subject brings the animals to the slaughter (which is generally integrated also). The farmer is paid according to the feed conversion ratio achieved.

1.2 LCA applied to poultry production

As many are heads of broilers bred in the North - East of Italy, and consequently the amount of poultry manure produced, it is presumed that many are the environmental impacts that result from them. This assessment requires a quantification of emissions and resources throughout the life cycle of that product. Life Cycle Assessment (LCA) is a generally accepted method for assessing environmental impact throughout a product's life cycle (Guinée et al., 2002). Many studies have used the LCA method to assess the environmental impact of animal products such as pork, chicken, beef, milk, or eggs. There are studies that often evaluate the impact of a single product or activity, without comparing different management to have a farm with less impact on the environment. This theme in particular is related to the use of resources and soil. However, reported LCAs comparisons were made between animal products from OECD countries (Table 1.2).



Study	System/study case	Country[a]	FU[b]	GWP	AP		EP		Land	Energy
				kg CO_2-e	kg	unit	kg	unit	m^2	MJ
Pork										
Zhu-XueQin and Van Ierland (2004)[c]	Conventional	NL	t protein	77,883	675	NH_3-e	2491	N-e	55,000	397,252
Basset-Mens and Van der Werf (2005)	Good agricultural practice	F	kg live weight	2.3	0.044	SO_2-e	0.021	PO_4^{3-}-e	5.4	16
Basset-Mens and Van der Werf (2005)	Red label	F	kg live weight	3.5	0.023	SO_2-e	0.017	PO_4^{3-}-e	6.3	18
Williams et al. (2006)	Heavier finishing	UK	t dead weight	6080	391	SO_2-e	97	PO_4^{3-}-e	6900	15,500
Williams et al. (2006)	Indoor breeding	UK	t dead weight	6420	507	SO_2-e	119	PO_4^{3-}-e	7300	16,700
Williams et al. (2006)	Outdoor breeding	UK	t dead weight	6330	362	SO_2-e	95	PO_4^{3-}-e	7500	16,700
Williams et al. (2006)	Conventional	UK	t dead weight	6360	395	SO_2-e	100	PO_4^{3-}-e	7400	16,700
Cederberg and Darelius (2002)	Single intensive pig farm	S	kg bone–fat-free meat	4.8	2.6	mol H^+-e	2.0	O_2-e	15	22
Blonk et al. (1997)	Conventional	NL	kg live weight	3.7	0.031	SO_2-e	0.018	PO_4^{3-}-e	–	16
Chicken										
Williams et al. (2006)	Conventional	UK	t dead weight	4570	173	SO_2-e	49	PO_4^{3-}-e	6400	12,000
Williams et al. (2006)	Free range	UK	t dead weight	5480	230	SO_2-e	63	PO_4^{3-}-e	7300	14,500
Katajajuuri (2008)	Conventional	F	t live weight	2079	35	SO_2-e	2.1	PO_4^{3-}-e	5500	16,000
Beef										
Williams et al. (2006)	100% suckler	UK	t dead weight	25,300	708	SO_2-e	257	PO_4^{3-}-e	38,500	40,700
Williams et al. (2006)	Lowland	UK	t dead weight	15,600	452	SO_2-e	153	PO_4^{3-}-e	22,800	26,800
Williams et al. (2006)	Hill and upland	UK	t dead weight	16,400	510	SO_2-e	169	PO_4^{3-}-e	24,100	29,700
Williams et al. (2006)	Non-organic	UK	t dead weight	15,800	469	SO_2-e	157	PO_4^{3-}-e	23,000	27,800
Casey and Holden (2006)	Both specialist beef farms and dairy breeds	I	kg live weight	11	–		–		–	–
Cederberg and Darelius (2002)	Conventional, dairy calves	S	kg meat	17	4.2	mol H^+-e	3.4	O_2-e	33	40
Milk										
Basset-Mens et al. (2009)	Average farm	NZ	kg milk	0.93	0.0081	SO_2-e	0.0029	PO_4^{3-}-e	1.2	1.5
Cederberg and Mattsson (2000)	Single specialised farm	S	t ECM	990	18	SO_2-e	58	NO^{3-}-e	1925	2800
Cederberg and Flysjö (2004)	Production > 7500 ECM/ha	S	kg ECM	0.87	0.010	SO_2-e	0.0038	PO_4^{3-}-e	1.5	2.6
Cederberg and Flysjö (2004)	Production < 7500 ECM/ha	S	kg ECM	1.0	0.011	SO_2-e	0.0042	PO_4^{3-}-e	1.9	2.7
Haas et al. (2001)	Intensive	G	t milk	1300	19	SO_2-e	7.5	PO_4^{3-}-e	–	2700
Haas et al. (2001)	Extensive	G	t milk	1000	17	SO_2-e	4.5	PO_4^{3-}-e	–	1300
Casey and Holden (2005)	Average Irish dairy unit	I	kg ECM	1.3	–		–		–	–
Hospido et al. (2003)[c]	Two typical Galician dairy farms	ES	1 l packaged milk	1.1	0.0085	SO_2-e	0.0053	PO_4^{3-}-e	–	6.2
Thomassen et al. (2008b)	Ten conventional commercial dairy farms	NL	kg FPCM	1.4	0.0095	SO_2-e	0.11	NO^{3-}-e	1.3	5.0
Thomassen et al. (2009)	119 dairy farms	NL	kg FPCM	1.4	0.011	SO_2-e	0.12	NO^{3-}-e	1.3	5.3
Williams et al. (2006)	Non-organic	UK	10,000 l milk	10,600	162	SO_2-e	63	PO_4^{3-}-e	11,900	25,200
Williams et al. (2006)	More fodder as maize	UK	10,000 l milk	9800	164	SO_2-e	61	PO_4^{3-}-e	11,800	23,600
Williams et al. (2006)	60% high yielders	UK	10,000 l milk	10,200	159	SO_2-e	60	PO_4^{3-}-e	11,400	24,200
Williams et al. (2006)	20% autumn calving	UK	10,000 l milk	10,300	159	SO_2-e	65	PO_4^{3-}-e	12,100	23,400
Eggs										
Mollenhorst et al. (2006)	Battery cage	NL	kg egg	3.9	0.032	SO_2-e	0.25	NO^{3-}-e	4.5	13.0
Mollenhorst et al. (2006)	Deep litter	NL	kg egg	4.3	0.057	SO_2-e	0.31	NO^{3-}-e	4.8	13.4
Mollenhorst et al. (2006)	Deep litter with outdoor run	NL	kg egg	4.6	0.065	SO_2-e	0.41	NO^{3-}-e	5.7	13.9
Mollenhorst et al. (2006)	Aviary with outdoor run	NL	kg egg	4.2	0.042	SO_2-e	0.35	NO^{3-}-e	5.1	13.7
Williams et al. (2006)	Non-organic	UK	20,000 eggs	5530	306	SO_2-e	77	PO_4^{3-}-e	6600	14,100
Williams et al. (2006)	100% cage	UK	20,000 eggs	5250	300	SO_2-e	75	PO_4^{3-}-e	6300	13,600
Williams et al. (2006)	100% free range	UK	20,000 eggs	6180	312	SO_2-e	80	PO_4^{3-}-e	7800	15,400

[a] NL = The Netherlands; F = France; UK = United Kingdom; G = Germany; I = Ireland, F = Finland; ES = Spain, S = Sweden, NZ = New Zealand.
[b] FU means functional unit; ECM = Energy corrected milk; FPCM = fat–protein corrected milk.
[c] System boundaries from cradle to grave.

Table 1.2: Characterization and potential Greenhouse Gas (GWP), potential Acidification (AP), potential Eutrophication (EP), soil and energy use of pigs, poultry and cattle (modified by M. de Vries and I.J.M. de Boer, 2010).

However, these comparisons have revealed that the results do not include the environmental consequences of competition between animals and men for land use and resources. Furthermore, attention has not been paid in general to the impact of livestock farming on the environment as a whole. Having a broader overview of livestock activity, it is possible to have consequences on it also. For these reasons, Climate Change is a growing problem: temperatures increase, precipitation patterns change, ice and snow melt and the global average sea level is on the rise. These changes are expected to continue and extreme climate events such as floods and droughts will become more frequent and intense. It is highly likely that most of the heating since the middle of the 20th century is due to the observed increase in greenhouse gas concentrations due to emissions from human activities (included livestock). Global temperature has risen by about 0.8 °C over the past 150 years and is expected to increase further. In Italy, a higher temperature was observed than the world average at +1.5 °C compared to +0.6 °C worldwide (Brunetti et al., 2005). A rise above 2 °C compared to pre-industrial temperatures increases the risk of dangerous changes to global human and natural systems. The United Nations Framework Convention on Climate Change (UNFCCC) has set the objective of limiting the rise in global average temperature over the pre-industrial period below 2 °C.

1.3 GHG emissions from poultry

The effect of different greenhouse gases on Global Warming is expressed mostly as the Global Warming Potential (GWP) of each gas. This is a measure of how the various greenhouse gases have an impact on the climate. The reference unit is CO_2 equivalent. Greenhouse Gases (GHGs), whether they are of anthropic or natural origin, absorb and emit radiation to specific wavelengths within the spectrum of infrared radiation emitted from the Earth's surface, the atmosphere and the clouds (ISO, 2006). The main GHGs are (Figure 1.4): carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), sulfur hexafluoride (SF6), alocarbons.

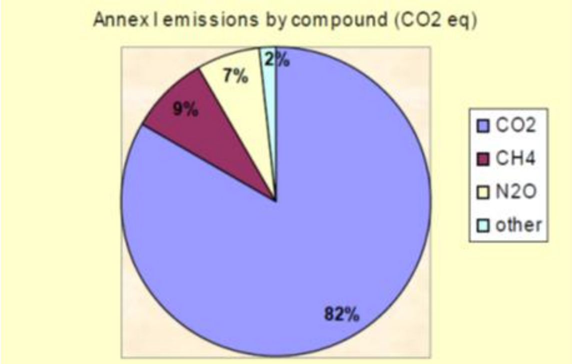


Figure 1.4: Contributions of different greenhouse gases to global warming (UNFCCC, 2005).

According to the latest Intergovernmental Panel on Climate Change (IPCC) report, climate warming is an unequivocal phenomenon, but it has been shown that by reducing greenhouse gas emissions at concentrations that will stabilize the global average temperature increase to 2 °C can significantly limit damage to ecological, social and economic systems globally (IPCC, 2007a). That is why the reduction of greenhouse gas emissions is now considered a priority issue and is at the center of political and institutional debates. Many actions have been taken at various levels to mitigate climate change by imposing global emission reduction targets. In particular, regarding the livestock in Italy, the environmental impacts that cause climate change are caused by livestock breeding. Breeding in general is a system that allows a proportion of primary land production of feed fo animals, and which entails the genesis of output to be treated, which results in faecal and urinary excretions, in the gas eruption and the use of natural resources. In this complex scheme, the livestock system affects the status of the various environmental components, having different input and output interactions with these. If we take into account that almost 5.7 million cattle, 615 thousand pigs and 254 million poultry (ISTATd, 2013) are slaughtered in Italy (and therefore have been bred) during the year and even more that they include the whole livestock sector, it is conceivable to think how inputs and outputs are quantitatively very relevant. In a context in which PAC assistance from 2014 will be even more closely linked to the implementation of environmentally sustainable practices in which the entire country system is compelled to respect the European objectives set out in Plan 20-20-20 by 2020, and in which the Italian consumer's environmental awareness is rising, more than 50% claim to have a good or good awareness of the issues of eco-sustainability of products (Cancila, 2010). So, it is crucial to have a picture of impacts and the interactions between livestock and the environment. With regard to emissions from farms that cause environmental impacts, they concern air, water and soil. The main greenhouse gases are water vapor, CO_2, CH_4 and N_2O. Except for the first, others are of livestock interest: water vapor, in atmospheric concentration, is not significantly influenced by human activities, thanks to the high speed of the hydrologic cycle also (Giuliacci and Corazzon, 2005). For the remaining three compounds, an increase in their concentration in the atmosphere has been observed since the timely measures of these gases started (in 1958 at Mauna Loa, Hawaii), causing an increase in the effects of the greenhouse effect. To date, there is no doubt that such upward trends are mainly due to human action and, in particular, to emissions related to human activities (IPCC, 2007). Compared to the emission of CO_2, CH_4 and N_2O into the atmosphere, the livestock system makes a major contribution: worldwide it is estimated that the livestock sector, directly and indirectly, is responsible for the emission of 9% CO_2, 40% CH_4, 66% N_2O (FAO, 2006). However, it should be noted, that the contribution of the Italian agro-zootechnical sector to total greenhouse gas emissions (expressed as CO_2 eq.) has decreased by about 10% between 1990 and 2006 (Coldiretti, 2003). Regarding the CO_2 is the greenhouse gas most present in the atmosphere, removed the water vapor. The most recent data set its concentration to 400 ppm (NOAA measure in May 2013 at Manua Loa site), up by 3 ppm compared to 12 months earlier. Its emission is mainly due to the use of fossil fuels, and the continual increase in their use by humans to support the socio-economic structure has brought the concentration value from about 280 ppm pre-industrial to 400 ppm today (data NOAA). Unlike water vapor, CO_2 (like other major greenhouse gases) has a much longer persistence in the atmosphere, due to a much lower biogeochemical cycle speed. Moreover, anthropogenic emissions - 5.5 Gt ± 0.5 to 2005 and increasing (Giuliacci and Corazzon, 2005) are not offset by the phenomena of CO_2 removal from the atmosphere, photosynthesis and ocean absorption, although these are quantitatively increasing due to the concentration of gas (Mahli, 2002). In fact, it is estimated that only 60% of human emissions have been offset by storage in natural tanks, soil and oceans, while 40% have contributed to the increase in atmospheric concentrations (IPCC, 2001). The CO_2 cycle in livestock activity follows the flow below (Figure 1.5).

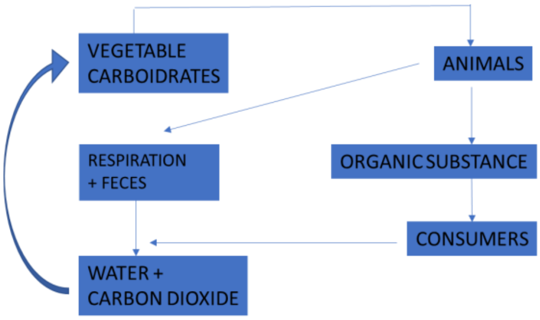


Figure 1.5: Carbon dioxide (CO_2) cycle in livestock activity.

The livestock sector has to be divided into three subcategories with respect to the contribution to CO_2 emissions: animal, relating to CO_2 inputs resulting from the direct and indirect use of fossil fuels for the operation of the breeding system and change in soil use. Compared to the "animal" subcategory, then the totality of the animals, their net contribution is zero since, as the animal is inserted into trophic ecological dynamics, the quantities released are equivalent to those previously extracted for plant production of food (FAO, 2006). However, the second subcategory is relevant, CO_2 inputs resulting from the direct and indirect use of fossil fuels for the operation of the breeding system. The CO_2 factor has little impact on the other two greenhouse gases, CH_4 and N_2O, on the total of livestock emissions in general. The third CO_2 emission factor for the livestock sector is that of land use change. The production of the food necessary for the diet of animals requires new soil compared to that intended for obtaining vegetable food consumed directly by humans; this involves the conversion of extensive grasslands with natural vegetation, meadows and forests, to cultivated plots. To date, in the Veneto, the agricultural area used (AAU) for animal feed production is around 50-60% of the total, while in Lombardy and Piedmont it reaches 70-80% (Lesschen et al., 2011). Changes in soil use cause CO_2 release into the atmosphere because the loss of natural vegetation, especially when it comes to forestry, results in a change in the microclimate of the first layers of soil, which becomes warmer due to increased sunlight; this causes an increase in the metabolic rate of degrading microorganisms, resulting in an increase in the aerobic fuel consumption of carbon-based organic matter stored in the soil (FAO, 2006). This component can not be overlooked: although the pressure on the production of additional livestock products is only part of the cause of the new virgin surface production, it is estimated that 33% of the CO_2 emissions are due to land use change (IPCC, 2001). Instead, with respect to CH_4, its contribution to the release of methane into the atmosphere is mainly related to the management of the waste. The production of CH_4 is due to the fact that the conditions within the waste are mainly anaerobic, an environment in which bacterial degradation produces such a compound (FAO, 2006). The waste may be in a palatable form (solid manure) or non-palatable (slurry). The different physical state influences the environment in which the bacterial flora is present in the waste: the solid manure has a porousity not present in the slurry, which leads to better oxygen presence and inhibis the production of CH_4 (FAO, 2006). Other important factors are the storage temperature, the present energy content, time and storage modes (FAO, 2006). On the other hand, N_2O is about 296 times as effective as CO_2 in retaining energy from Earth's surface, but its concentration in the atmosphere is much lower, about 310 ppb (FAO, 2006). The production of this compound due to the livestock sector is not directly related to the animal husbandry but to the production of the food necessary for it and the waste management. N_2O production occurs mainly in soil, in an anaerobic environment, as an intermediate product of bacterially mediated denitrification processes, which is not reduced to the final form N_2 by evaporating into the atmosphere. The concentration of this gas is growing, mainly as a result of increased nitrogen input to the soil, through chemical fertilizers and the spread of livestock wastes. The increased nitrogen availability, which is not completely intercepted by crops, entails a strengthening of the bacterial processes associated with this element, including the release of N_2O in the denitrification process (FAO, 2006).

1.4 Ammonia emissions

Ammonia (NH_3) produced by the livestock sector mainly arises from waste management, due to the presence of nitrogenous substances in them. Within the waste, NH_3 is produced through a reaction by which certain bacteria obtain nitrogen from the complex nitrogen compounds, which is then used for their anabolic processes. NH_3 is a volatile compound at room temperature, whereby liquid-to-gaseous transition is observed, within a complex equilibrium between gaseous, liquid and NH_4^+ (acid-base balance). During the atmospheric phase, NH_3 undergoes a series of oxidation reactions involving the formation of nitric acid which, together with the sulfuric acid, is deposited on the soil through the damp or dry deposition phenomena in the form of gases or particles; this deposition is significant in terms of environmental impact as it involves phenomena of acidification of soils and surface water, with repercussions on the organisms that live there (FAO, 2006). Deposition, already in the nineties, surpassed the critical point of balance of the natural system in about 7-18% of the semi-natural ecosystems (Bouwman and van Vuuren, 1999).

1.5 Nitrate, waters and soils

With regard to the water, the surface and groundwater of the regions characterized by the presence of livestock farms are subject to negative pressures. The spreading of agricultural waste into the soil involves the introduction of nitrogenous substances in considerable quantities, which must be added to nitrogen fertilization and deposition of NH_3 and other compounds. This input of anthropic nature adds to the natural input linked to the bacterial-mediated biological fixation phenomena, and then enters the biogeochemical nitrogen cycle, leading to an alteration of existing equilibria (FAO, 2006). Soil nitrogen is partially absorbed by plants through radicals, while the rest is organic or mineralized. Degrading microorganisms are responsible for mineralization processes, while organic nitrogen is derived from the more or less degraded animal, plant and microbial dead tissue that make up the organic matter of the soil (FAO, 2006). Nitrogen inputs with waste and fertilizers used for the production of livestock foods may cause saturation of the system's ability to use living organisms (plant absorption, denitrification processes) or store it as an organic substance in the soil more than a significant proportion of nitrogen is present in small molecules and can be quickly mineralized, primarily urea. This implies that an important proportion of inorganic nitrogen, in the form of nitrate, can be transported from infiltration and surface water flow to surface water bodies and groundwater (FAO, 2006). If in underground bodies high concentrations of nitrate cause toxicity problems with regard to drinking water use, the main problem involving increasing the presence of nitrogen, together with phosphorus, in surface water is eutrophication. This phenomenon mainly accounts for stagnant water bodies where high concentrations of nutrients usually limit plant growth, such as nitrogen and phosphorus (in the case of phosphorus, also present in livestock waste, in smaller quantities but being less leachable). The abundance of nutrients allows rapid and consistent algal growth, which, as organisms die, increases the suspended and sedimented biomass growth; the subsequent aerobic decomposition of algal tissues, carried on by various species of microorganisms, causes anoxia conditions that are deleterious to many animal species: the "dead zones" are observed. These have negative development at a productive, tourist also, recreational level (Ongley, 1996; Carpenter et al., 1998; Belsky et al., 1999). Intervention already at livestock level, improving production and nutritional parameters to limit the presence of nitrogen in animal excretions, and then in subsequent levels, with best storage, treatment, and fertilization practices, helps to reduce the problem of leaching and percolation nitrogen and the resulting pollution of water bodies (FAO, 2006). With regard to the soil, livestock intervenes to change both soil as a natural resource, its composition and the chemical-physical-biological characteristics, both the use and the resource being made. For these reasons, it is fundamental to evaluate how the elements that are introduced into the ground and which enter in the air-water-soil circle also, must be evaluated. Therefore, a research was developed not directly related to the environmental impact of broiler breeding, but related to the introduction of nutrients, especially with regard to nitrogen.

1.6 Phosphorus

The most obvious environmental quality problems affecting the soil are phosphorus accumulation, loss of natural habitat, and impact on small and large spatial biodiversity. More precisely, a substantial part of the problems mentioned are not directly related to the livestock system, but to the agricultural production of livestock foods. Waste management does not only concern nitrogen and environmental issues due to the increase in reactive nitrogen forms in the soil-water system, but also phosphorus. It is present in the form of phosphate both in organic and inorganic compounds in large part, it is another component significantly present in animal manure, which once reached the soil through the spreading action, enters the complex reactions of its biogeochemical cycle. If soil input, like nitrogen, is aimed at agronomic use, the interaction of phosphate with the soil-water system differs from that of nitrogen. The nitrification processes lead to the formation of NO_3^-, which has low affinity with the soil and hence, little hold of this, is readily available to the transport of water flowing in the first centimeters of soil or to the aquifers; the phosphate, PO_4^{3-}, has a greater affinity with the organic and inorganic compounds that make up the soil, resulting in much more retained and less available at leaching. The intensive application of livestock waste on agricultural soil is, as in the recent past, superior to phosphorus intake, to those which are the radical absorption capacities; already a decade ago phosphorus deposition rates in the US and in many European countries were estimated at 8 to 40 kg P_2O_5/ha/year (Carpenter et al., 1998). Another estimate, almost contemporary, showed how the rates of application exceeded the average rate of removal by vegetation based on the characterization of land use in the UK of a factor of 2 to 15 times (Hooda et al. al., 2001). This accumulation can lead to saturation of the soil's ability to hold phosphorus and thus lead to increased runoff and leaching of the element and lead to potential contamination of nearby water bodies (James et al., 1996). This has implications for the phenomenon of worsening water quality in general and eutrophication, mentioned above.

1.7 Biodiversity

Land use transformation, linked to the needs of livestock systems, not only triggers new processes related to the release of carbon dioxide due to the accelerated degradation of the organic matter, but it has also effects on biodiversity. Over the last decades, global biodiversity loss has been observed on unprecedented scale and agricultural intensification has been one of the main drivers of this global change (Matson et al., 1997; Tilman et al., 2001). If, over time, conservation has shifted from the protection of individual species to that of whole ecosystems and the establishment of individual protected areas isolated to the creation of protected ecological networks, of which the Natura 2000 Network of the European Union is an authoritative example, there is also an awareness that this policy is not entirely exhaustive in combating the loss of biological diversity (Collins and Qualset, 1999; Bengtsson et al., 2003; Schroth et al., 2004) that the changes needed in areas with a different degree of disturbance should also be studied, such as the areas cultivated: reinforcement effects on biodiversity and ecosystem functions have also been observed through particular types of farming management (Jackson and Jackson, 2002; Rosenzweig, 2003). In addition, agricultural areas are part of a landscape that may be more or less complex, ie comprising a more or less variegated patchwork of disturbed areas and more natural areas. Several data indicate that the long-term sustainability of ecosystems and their services depends to a great extent on the conservation of biodiversity at a landscape scale (Bengtsson et al., 2003). The impact of agronomic practices such as conversion from conventional agriculture to organic farming (Roschewitz et al., 2005) or the creation of highly natural buffer zones at the boundaries of plots (Thies and Tscharntke, 1999; Tscharntke et al., 2002) on the enhancement of biodiversity between modified areas and unmanaged control areas has been positive. Positive effects result from a remodeling of soil fertilizer inputs also, which should be closely linked to local needs and efficient management of mechanical machining and pesticide use (McLaughlin and Mineau, 2005). Increases in biodiversity, through precise measures such as those mentioned above, can be achieved without affecting the flow of productive agricultural output on which the farmer's income is based (Omer et al., 2006).

CHAPTER II

THE ENVIRONMENTAL IMPACTS OF BROILER PRODUCTION SYSTEMS IN NORTH-EAST OF ITALY USING MICROORGANISM TREATMENTS WITH THE LCA APPROACH

2.1 Introduction

Low feed conversion ratios achieved in the broiler sector make poultry production one of the most efficient means of producing terrestrial animal protein (Flachowsky, 2002). A recent UK study on the impact of several animal species showed that poultry resulted as the most environmentally efficient livestock product when compared to the resources used in the production of beef, sheep meat and milk (Williams et al., 2006). However, the sheer scale of this industry necessitates close attention to a range of potential environmental impacts. Air emissions from poultry production are numerous and may include, methane (CH_4) and nitrogenous compounds in particular dinitrogen monoxide (N_2O), including ammonia (NH_3) (Wathes et al., 1997; Takai et al., 1998; Seedorf et al., 2000). NH_3 is a potential source of N fertilizer, environmental pollutant and odorant. A major effort for meat bird management is to reduce NH_3 volatilization from poultry manure through creating a better growing environment for the birds. High concentrations of NH_3 result in poor performance in birds, in particular of broilers (Deaton et al., 1984; Wang et al., 2011; Ahmed et al., 2014) and research suggested that 25 ppm NH_3 should not be exceeded in poultry houses (Carlile, 1984; Moore et al., 1996). Furthermore, stated that NH_3 at 20 ppm reduced body weight and feed convertion efficiency (Wijaya, 2000; Santoso et al., 2001). Finally, reduce NH_3 volatilization retain

N in poultry manure for fertilizer value, and it retains NH_3 that would otherwise be lost in the air. Since the 1950s there have been attempts to inhibit NH_3 volatilization from poultry manure, as an important part of emissions control (Cotterill and Winter, 1953; Nahm, 2005). A range of chemical and biological additives are known to reduce NH_3 volatilization from poultry manure (Van Der Stelt, 2007). They can be divided, according to their modes of action, into five groups (McCrory and Hobbs, 2001): (i) Digestive additives are amendments which enhance the biodegradation of manure and consists of microbial strains and/or enzymes, (ii) Acidifying additives (Dewes, 1996), (iii) Adsorbing additives, (Lefcourt and Meisinger, 2001; McCrory and Hobbs, 2001), (iv) Urease inhibitors (Sommer and Husted, 1995) and (v) Saponins. Excluding the first group, all others are chemical additives to reduced NH_3 volatilization which have been classified into two categories by Carlile (1984): those that act to inhibit microbial growth and those that combine with and neutralize NH_3. However, these and other chemical additives with trace elements, such as Cu and Zn, may have issues for plant toxicity and environmental contamination. Instead, using the first group (i) Digestive additives, these problems with chemical additives do not exist. For these reasons and for the fact that when (i) Digestive additives were tested, mostly concerned slurry of pigs and not poultry manure, it was interesting to evaluate the effectiveness of some of this group. Marketing statements generally claim that volatilization of NH_3 is reduced by stimulating immobilization of NH_4 by microorganisms, thus reducing its concentration in livestock (Mccrory et al., 2001). Grubbs (1979) claimed that the key to successful bacterial additives was for the added cultures to become the dominant strain within the microbial community. Most of the scientific work of Digestive additives includes probiotics and prebiotics (Patterson et al., 2003). A variety of microbial species have been used as probiotics, including species of Bacillus (Chiang et al., 1995; Endo et al., 1999), Bacillus Amyloliquefaciens (Ahmed et al., 2014), Bifidobacterium, Enterococcus, E. Coli, Lactobacillus (Chiang et al., 1995; Endo et al., 1999), Lactococcus, Streptococcus (Chiang et al., 1995). Whereas species of Bacillus, Enterococcus, and Saccharomyces yeast (Endo et al., 1999) have been the most common organisms used in livestock (Simon etal., 2001; Patterson et al., 2003). However, there has been at increase in research on feeding Lactobacillus to livestock (Gusils et al., 1999; Pascual et al., 1999; Jin et al., 2000; Tellez et al., 2001; Patterson et al., 2003). Often the products available in the market relate to a set of microorganisms and/or enzymes (Van der stelt, 2007; Alama et al., 1995; Li et al., 2001). An interesting application of Bacillus to reduce NH_3 in poultry house, concerning the Bacillus Subtilis (Santoso, 1999). Finally, another interesting application of Bacillus with modes of application and action similar to those applied in this research, concern MicroTreat P® (Karunakaran, 2008).

2.2 Aim of the work

The present work the analyzes in a Life Cycle Assessment (LCA) key the results obtained from the use of a digestive product in broiler farms with regard to NH_3 emissions.

The LCA method has been chosen by numerous authors to conduct environmental assessment for poultry production at the farm stages (Baumgartner et al., 2008; Bastianoni et al., 2010; Bengtsson and Seddon, 2013; Boggia et al., 2010; da Silva et al., 2012; Katajajuuri, 2007; Pelletier, 2008; Wiedema et al., 2008; Williams et al., 2006). In addition, different rearing scenarios (organic and conventional) have been compared from an environmental perspective in an attempt to define the best option (Boggia et al., 2010). Definitely, LCA is a tool used for identifying hotspots in the production chain which may give opportunities for lowering environmental impacts while improving efficiency and profitability (Djekic I. et al, 2014; Eide MH, 2012). An in-depht bibliographic survey showed a substantial lack of studies, with LAC approach, on the environmental performances deriving from the use of micrprincipal to reduce emissions from livestock, in particular those of broilers.

More in detail, in this paper we tryed to answer the following questions:

- how can the microorganisms that interfere with the nitrogen cycle, reduce environmental impacts of poultry production and especially the emissions of NH_3?
- is the treatment using such microorganisms directly on the poultry manure or through the drinking water more effective in reducing environmental impacts?

The application of the LCA methodology “from cradle to farm gate” is therefore aimed to quantify the environmental burdens of broiler production when each of these treatments is applied, and hence, to identify the main opportunities for reducing these impacts within each management scenarios. Definitely, the purpose of this research is therefore to assist the broiler industry, in targeting effective rearing management for environmental performance, as well as inform appropriate regulatory initiatives.

2.3 Material and Methods

2.3.1 Experimental Setup Treatments

The LW study was conducted in a farm in Northen Italian broiler standard indoor system per 7 cycle for a duration of 2014/2016 years. The selected birds were male broilers with a minimum growing cycle of 55 days. In the farm, male broiler were bred to obtain light chickens of an average weight of 2.2 kg and heavy chickens of an average weight of 3.4 kg. Broiler chicks were placed into floor pens at a approximately density of 13.6 bird/m^2 at the beginning of the cycle and 12.8 bird/m^2 at the end of the cycle. The bedding consisted of clean pine wood shavings at a depth of 10 cm. There were three scenarios becouse we have two treatments, Trial 1 sprayed the LW in the poultry manure (PM) and Trial 2 through the drinking water (DW). Furthmore, test was the same as control (CL) except for the addition of LW. In the experiment have been carried out forty-two replications total. Table 2.1 shows the main treatment designations for the study including the number of replications and number of birds delivered treated with LW to determine the effect when LW applied to poultry manure and drinking water.

Treatment	Replications	Number of birds	LW applied
PM	15	227.096	Poultry manure
DW	9	122.298	Drinking water
CL	18	271.348	Control

Table 2.1. Main treatment designtions, including replications and number of birds delivered, to determine the effect of LW applied to poultry manure (PM) and drinking water (DW) on environmental impacts, in particular NH_3, of broiler standard indoor system.

Based on the classification approach of McCrory and Hobbs (2001) the product, generally called LW for the confidentiality of the manufacturer, can be classified as Digestive additive. It was applied to the poultry litter either directly or through the drinking water and comparing the results with non-LW controls.

The LW consist of Bacillus Licheniformis, Bacillus Cereus and yeasts that are extract of fermentation from thermally dried microorganisms, other types of organisms, dextrose, sodium chloride and sodium bicarbonate. The product, as declared, contains additives with nitrifying bacteria that have the potential to reduce poultry manure NH_3 and/or NH_4^+ levels as bacteria oxidize them to nitrite and nitrate, NO_2^- and NO_3^-, respectively (Jacobson et al., 2001; Kim et al., 2004; Patterson, 2005). It contains denitrification bacteria that convert nitrates into gaseous nitrogen (N_2) also and/or stimulating immobilization of NH_4^+ like demonstrated by (Mccrory et al., 2001). Specially, always as supported, bacteria of the LW product produce broad spectrum antimicrobial proteins active against gram (-) bacteria. However, not much is known about the effectiveness of these additives on NH_3 volatilization from poultry manure. There are not probably scientific works about using the components of this product. In particular, with regard to Bacillus Cereus, work has been carried out to evaluate its effect on feed efficacy and to counteract infections (Gil de los Santos et al., 2005; Li et al., 2009). Instead, with regard to Bacillus Licheniformis, it has been tested to evaluate reduction of NH_3, but concerns slurry of pig (Lim et al., 2015). Studies of the effect of these microorganisms and more generally, of (i) Digestive additives group, mainly concern microbiological aspects.

The timing of the application directly on poultry manure was at the beginning of the production phase, half of the production cycle and finisher for each shed treated. Regarding the drinking water treatment, the applications took place once a week.

In each of the two trials, the LW solution was sprayed to dropping to the surface of the poultry manure and through drinking water. In the Trial 1, there were fifteen replications of PM with doses of application of 1.0 kg cycle (at 15 days)/1,000 m^2, 2.0 kg cycle (at 25 days)/1.000 m^2 and 3.0 kg cycle (at 35 days)/1.000 m^2 in a single solution. In the Trial 2, there were nine replications of DW. The drinking water was supplemented once a week with 10 gr of LW/liter of water. Feed and water were supplied ad libitum to each shed. NH_3 levels were measured with a Drager tubes (Drager GmbH, Lubeck, Germany) utilizing low-range NH_3 detector tubes (NH_3 2/a). NH_3 sampling (mg/m^3) was conducted three times per shed per cycle. Sampling was done after four days of treatments on PM for the first sampling, then before the thinning (to get the light chickens) and finally, ten days before the end of the cycle. The same timing was used for DW treatments and for CL also. The sampling has taken place at approximately the same time and location within each pen. The NH_3 sampling points followed a pattern, in order to have a maximum representation of the NH_3 present in each shed (Figure 2.1).

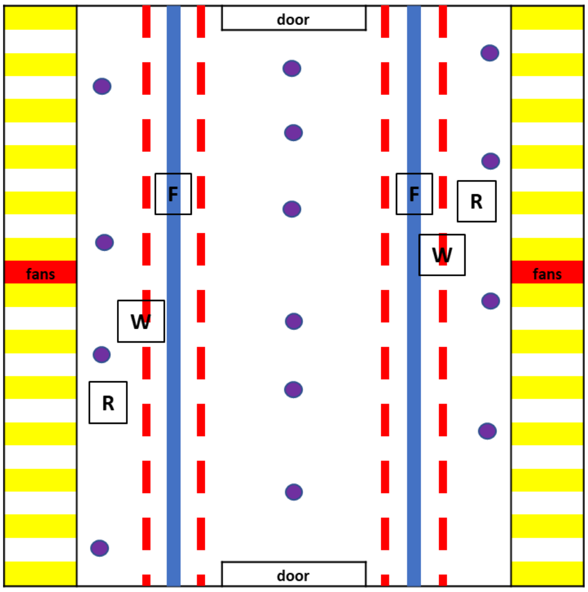


Figure 2.1: Schematic layout of one shed, showing in total 2 stripes of feeding lines (F), 4 watering lines (W), and 7 remaining areas (R). During the study, 14 air samples (purple pollens) were collected in three moments in each shed (modified K. von Bobrutzki et al., 2013).

Samples were taken at approximately 10 cm above the poultry manure. Furthermore, at each visit samples of air were colected (tools) from alternate fans in each shed from outside the building. The total flow of air exhausted from each shed was computed from the cross-sectional of area of each fans outlet (seven per shed) and the average velocity of the air emerging from each: the velocity was calculated from five measurements with an anemometer at different points in each cross-section (Sgorlon E., Guercini S., and Iob L. 2017. Unpublished data). These measurements of NH_3 were carried out in three replics during each cycle, for each breeding shed (total of 6 sheds), for a total of 7 cycles. The detection of NH_3 emissions was punctual, then the weighted average of the different measurements was calculated and put in relation to the air flow that circulated inside the shed. While, as regard total CH_4 and N_2O emissions, the calculation was based on Tier 1 Method (IPCC, 2006). Finally, before this management practice can be put into widespread usage, questions concerning the environmental impact of these different treatments in broilers on commercial farms must be addressed. For this reason, the Life Cycle Assessment (LCA) method has been considered the most appropriate.

2.3.2 General principles of Life Cycle Assessment (LCA)

This work was developed using SimaPro 8.0.3.14 software (PRé Consultants, 2013) and related databases, following an international methodology. International standards have been developed to specify the general framework, principles and requirements for conducting and reporting LCA studies (ISO 2006a: 14040; ISO 2006b: 14044; 14048; BSI, 2006). The general structure includes four aspects: i) Goal and scope definition; ii) Inventory analysis; iii) Impact assessment and iv) Interpretation. The results are reported in the most informative way possible and the needs and opportunities to reduce the impact of the product(s) on the environment are systematically evaluated against the study's goal.

2.3.3 Goal and Scope definition

The goal of this work was to apply the LCA method from ''cradle to farm gate" to assess the environmental impacts of microorganisms LW in order to reduce the emissions of NH_3 in particular, but N_2O and CH_4 also, from Northern Italian broiler standard indoor system, and therefore, to identify possible opportunities for reducing environmental impacts within the management systems. Two LW microorganism treatment were considered, sprayed the LW in PM and DW. The overarching objectives of this project include: quantifying the environmental impacts of Northern Italian standard indoor system; evaluating the possible effects of LW on the nitrogen cycle in particular; compare PM and DW treatments to evaluate what is most efficient in reducing on emissions and hence on environmental impact. In the Northern Italian broiler standard indoor system, 1 kilogram of broiler live weight (FU) was considered to be the functional unit similar to other authors (Williams et al., 2006; Leinonen et al, 2012, Wiedemann et al., 2012). For what concerns the scope definition of this LCAs, the following phases are analysed. An overview of the system boundaries of the model are illustrated in (Figure 2.2).

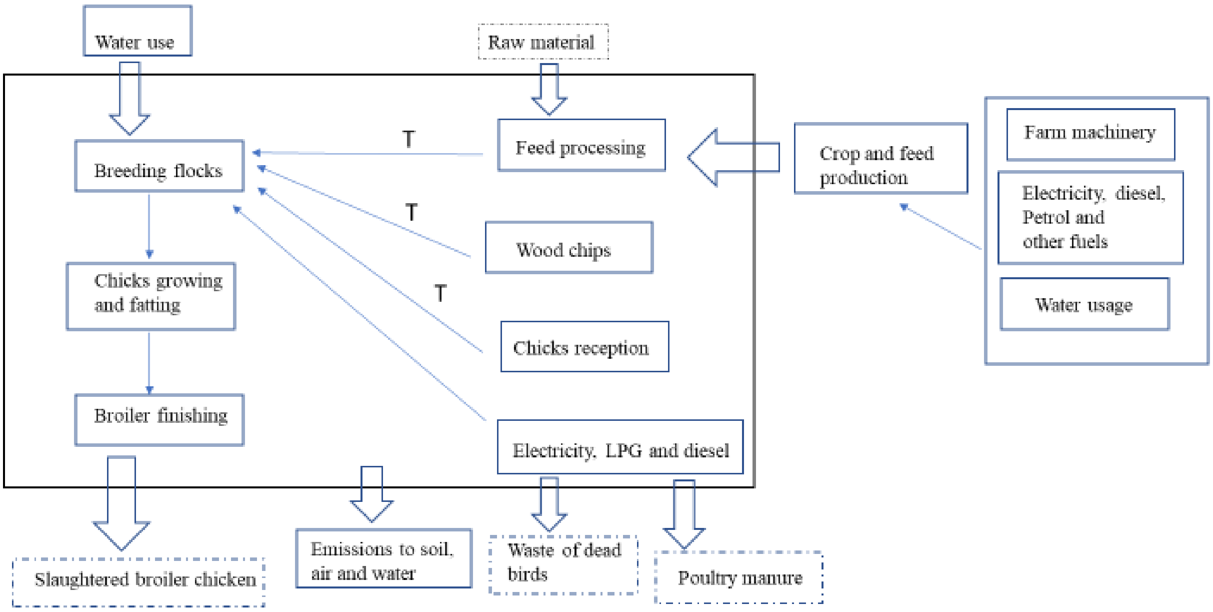


Figure 2.2: System boundaries and flow chart of the broiler standard indoor production system under assessment: solid boxes correspond to processes included in this study. Dotted boxes correspond to processes excluded from assessment.

The system boundary start included the crops that form the feed and their transport in the farm. In addition, LPG and diesel are used for heating and for the use of machinery employed during breeder cycles. It has been considered the type of bedding and its transport in the farm also, the consumption of drinking water and electricity used for lighting and ventilation both. Finally, we considered broilers of a 7 cycles in total, coming to the end of cycle and their average weight also (loading male broilers for slaughter). The following processes were excluded from the analysis: vaccines and antibiotics, cleaning agents (detergents and disinfectants) in agreement with other studies (Castanheiraet al., 2010; Hospido et al., 2003), processing and transportation infrastructure, disposal of mortalities, due to their minor contribution to the overall production system. The current work is not just for breeders, but the agri-environmental scientific community, and other stakeholders in the supply and consumption chain also.

2.3.4 Life Cycle Inventory (LCI)

In LCA studies, it is important consider real data in order to obtain representative and relevant environmental results. In this study, Life Cycle Inventory (LCI) data for PM, DW and CL scenerios was collected through surveys, interviews and visits to the farms. What changes in the different scenarios is just the use or not of LW microorganisms. All the primary data corresponded to years considered in the ‘’Experimental Setup Treatments’’. With regard to the implementation of the inventory, local data (related to Northern Italian) have been used where possible. When local data or primary data could not be used, data from the following databases was used: Ecoinvent 3 (Nemecek et al., 2004), Agri-footprint (Vellinga et al., 2013; Block Agri-footprint BV, 2014; BSI, 2012; Centraal veevoederbureau, 2010; USDA, 1973), ELCD v3.0 and USLCI v1.6.0. Table 2.2 shows the main data considered in the three scenarios.

Indicator		**CL**	**PM**	**DW**
shed treated	n°	18	15	9
average time of rearing	d	55,1	55,1	54,2
chicks	n°	287.090	238.200	133.367
chicks transport	kgkm	1.550.286	1.286.280	720.182
density	bird int/m2.cycle	13,8	13,6	13,5
density	bird del/m2.cycle	13,0	12,9	12,4
average mortality	%	5,8	4,8	8,1
average final weight	kg	3,4	3,4	3,3
feed consumed	kg	1.794.193	1.464.461	815.767
transport feed	kgkm	163.116.018	133.693.451	72.706.742
index conversion	kg feed/kg meat	1,94	1,92	2,00
water used	m^3/bird del.	14,5	17,6	17,9
bedding (clean pine wood shavings)	kg	112.010	93.304	54.686
transport bedding	kgkm	19.041.697	15.861.706	9.296.597
heat LPG	l/bird deliv.	0,207	0,206	0,206
electricity for ventilation	kWh/bird	0,77	0,78	0,88
electricity for feed augers	kWh	13.646	11.425	7.464
electricity for lighting	kWh	49.421	42.866	34.264
processing load/unload and mill of poultry manure with diesel	l	5.304	4.449	3.210
poultry manure	kg	410.548	314.349	170.103
NH_3 in air	kg	5.801	3.038	1.850
NH_3 in air	kg/bird	0,037	0,022	0,015
N_2O in air	kg	2.110	2.722	1.442
N_2O in air	kg/bird	0,002	0,002	0,002
CH_4 in air	kg	294	379	201
CH_4 in air	kg/bird	0,012	0,012	0,012

Table 2.2: Mean characteristics of the three scenarios. PM: sprayed the LW in the poultry manure, DW: LW through the drinking water, CL: control except the addition of LW. FCR: index convertion. *36 grams of chick for 150 km of transport, **80 km of feed transport, ***170 km of bedding transport. NH_3, N_2O and CH_4 are the emissions from the broiler farm considered.

The following inputs were considered: chicks and transport, bedding materials and transport, drinking water, feed and transport, electricity and LPG. These inputs contribute to produce the main product that is 1 kilogram of broiler live weight (FU). Regarding the transport, the unit enter in SimaPro was kg*km, so each path length was multiplied for the kilos of the delivered product. Activities start with the reception of chicks at the farm gate and their transport from the chicken hatchery to the farm has been considered for an average distance of 150 km. For the transport of chicks were considered EURO4 trucks with a capacity of 10 tonnes less, with an empty return (Klein et al., 2012a – 2012b). Chickens are housed in poultry beds, which are commonly composed of a clean pine wood shavings. Production of these bedding materials (USLCI, 2013; Dones et al., 2007; Werner et al., 2007; Nemeceket et al., 2004) as well as their distribution to the chicken farm was considered within the system. In addition, we considered the transport of wood shaving from the shop in Italy to farm also, with EURO4 trucks of 10-20 tonnes capacity and with an empty return (Klein et al., 2012a – 2012b) for an average distance of 170 km. Regarding drinking water consumption, the data set was considered a cradle to gate inventory for drinking water based on groundwater (Eplca, 2010; Technical purpose of product or process: potable water from groundwater for all kind of applications). It was considered this because the farm studied draws water from a shaft. According to several studies in which the environmental impacts of farm-related activities were identified (Castanheiraet al., 2010; Hospido et al., 2003), feed production is one of the main factors responsible for environmental damage, so a detailed description of the feed has been made. In this study, the average FCR (feed conversion ratio) was of 1.95 kg/kg. Four types of feed were used, one for each period of the growth cycle (Table 2.3).

Table 2.3: Feed composition, in %, for broiler (P.B.). P.B. 20 is administered in place of P.B. 2, only for genetic COBB 700.

		PB 12	PB 1	PB 2	PB 20	PB 3
Period (days of ages)		*1-10*	*11-25*	*26-41*		*42-46*
composition	Maize	44	45.1	36.7	42.1	39.5
	Sorghum	-	7	21	20	19.2
	Soybea nmeal	30	27.5	21	16	21
	Wheat grain	7	7	5	7	6.5
	Roasted soybeans	4	2	5	3	-
	Soybean oil	2	-	-	-	-
	Maize gluten	7	-	-	-	-
	Animal fat	-	4	5.5	4.7	6.5
	Sunflower seed	-	4	3	4.5	4.5
	Hydrolysed animal proteins from pigs	2	-	-	-	-
	Dicalcium phosphate	1	1	0.7	0.6	0.7
	Calcium carbonate	2	1.6	1.5	1.5	1.5
	Sodium chloride	0.2	0.1	0.25	0.25	0.25
	Baking soda	0.15	0.3	-	0.25	-
	Butyric acid	0.15	-	-		-
vitamins and additives	Vitamin A	0.5	0.4	0.35	0.35	0.35
	Vitamin E					
	Vitamin D3					
oligoelements	Manganous sulfate monohydrate					
	Zinc sulfate monohydrate					
	Ferrous sulfate monohydrate					
	Culpic sulfate monohydrate					
	Potassium iodide					
	Sodium selenite					

The first is called PB12 and it was used from the beginning up to 10 days of age, the second PB1 was from about 11 days to 25 days of age, the third PB2 up to about 41 days and the last one PB3 was used till the end of the cycle. The farmer provided consumption in feed as tons for each broiler production cycle. In order to trace the quantity of each component of the feed given to broiler, researchers, with the help of the pet food companies, calculated the energy balance of the feed. Thus, we could quantify each component of the feed given to broilers. As regard maize, the origin come from Italy. The crop production considered was (Pallière C., et al., 2011) and the transformation in feed the process created from Hans-Jorg Althaus and Anton Assumpciò “Swiss integrated production” was used, because it can be adapted to all local markets. The transport distance was only changed to 700 km. About sorghum, origin is Italian also. We take the same crop production of the maize (Pallière C., et al., 2011), but was considered a 30% less and the transformation in feed process was considered in Netherlands instead of the transoceanic process (Vallinga et al., 2013). For the soybean, it is imported from South America and therefore transoceanic transport must be considered (Block Agri-footprint BV, 2014; FAO, 2013; Vellinga et al., 2013). Other ingredient were wheat grain and maize gluten, and these two came from all over Italy also (transport equal to 700 km). About wheat grain, crop and transformation production come from Emilia Moreno Ruiz, Hans-Jorg Althaus and Gregor Wernet. Instead, the transformation production of maize gluten was (Galitsky, C., et al., 2003). Then, soybean oil, roasted soybean seeds and sunflower seeds came from South America (Brasil and Argentina), so the crop and transformation process was similar that soybean (Block Agri-footprint BV, 2014; FAO, 2013; Vellinga et al., 2013). Moreover, there were transformation processes animal fat (Block Agri-footprint BV, 2014; FAO, 2013; Vellinga et al., 2013) and hydrolysed proteins (modify Luske et al., 2009) from pigs reintroduced in Italy since 2013 (N. 142/2011; D. Lgs 186/2012). Then the little percentage of minerals, like dicalcium phosphate, calcium carbonate, sodium chloride, baking soda and butyric acid was added. As it was for chicks and wood shaving, for feed was considered the transport with EURO4 truck with a capacity higher than 20 tonnes with empty return also, from feed mill to farm for an average distance of 80 km (Klein et al., 2012a – 2012b). An important input that was used in farm is electricity. Electricity was used for lighting, for mechanical distribution of feed and for ventilation. For all, it was considered an Italian electricity process of production and supply. Use by medium voltage (1kV - 60kV) electricity customers without own electricity generators or transformers (e.g. at industry and SME), which use electricity directly from the grid (Eplca, 2010;

Process Data set: Electricity Mix; AC; consumption mix, at consumer; 1kV - 60kV). Furthermore, the LPG was considered as used for the heating of the sheds. We considered a LPG combustion in average industrial boiler, which, even with regard to American data, has been considered representative of the Italian situation also (USLCI, 2013). Finally, with regard to the energy used in farm, we considered the diesel used by the machinery for the load/unloading of bedding and poultry manure. For this, the same considerations apply to the LPG. Finally, the NH_3, N_20 and CH_4 measurements were performed in order to evaluate their concentration in the different sheds (PM, DW and CL) and in the different cycles. The measurements follow what has been in the ‘’Experimental Setup Treatments’’.

2.3.5 Life Cycle Impact Assessment (LCIA)

In the current work, the ReCiPe and method was used and the Midpoint characterization models has been calculated (Goedkoop et al., 2009). Of the eighteen impact categories that ReCiPe Midpoint have, have been applied the following categories of interest 1) climate change CC (kg CO_2 e.), 2) particulate matter formation PMF (kg PM_{10} e.), 3) terrestrial acidification TA (kg SO_2 e.). Furthermore, regarding ReCiPe method has been used Midpoint hierarchist (H). ReCiPe H is based on the most common policy principles with regard to timeframes and other issues (R. Tongpool et al., 2012). Instead, considered CML-IA baseline 3.01 baseline method to another two categories of interest 4) eutrophication EP (kg PO_4^-e.), 5) photochemical oxidation (kg C_2H_4 e.). These are considerably affected by derived emissions such as CH_4, N_2O and NH_3. Thus, these impact categories have been considered for assessment in this study for several reasons: i) LCA indicators for all of them are very well established (although there are still methodological differences which can hinder detailed comparisons of results from different researchers); ii) impacts derived from livestock production systems are very related with these impact categories (mainly CC, TA and EP due to CH_4, NH_3, NO_3 and N_2O derived from poultry manure production, handling and management) and iii) these impact categories are the most widely used in environmental studies regardless of the animal production system which can facilitate the comparisons (Beauchemin et al.,2010; Cedeberg and Stadig, 2003; Reckman et al., 2012). Among the steps defined within the LCIA stage of the standardised LCA methodology (ISO 14040, 2006), only classification and characterization were undertaken in this study. In addition, in order to evaluate energy consumption, has been used the Cumulative Energy Demand (CED) version 1.08 method (Frischknecht R. et al, 2003).

2.3.6 Uncertainty analysis

In order to have a clear comparison between the different scenarios (PM, DW, CL), a Monte Carlo analysis was applied to quantify the uncertainties associated with the environmental impacts. The distribution assigned to apply this analysis was the normal distribution, with the calculation of standard deviation (*SD*) and the average value (*AV*) from the data, because this study is about animal production, based on biological processes. However, in SimaPro, the statistical values are entered as *2*SD* (normal distribution) value in order to have an estimate for the upper and the lower value. The *SD* value needed in Monte Carlo analysis was calculated based on the weight of bird and to have a better idea of comparison, Analysis of Variance (ANOVA) between sheds was made, considering how the measurement in each shed changed in the different cycle. In ANOVA firstly, number of birds of each shed was multiplied for the average weight to get the total live weight of the shed, then the input value of each cycle was divided by the total live weight and the average of each shed and the total averages were calculated (so, the value is per 1 kilogram of broiler live weight - FU). These two values were needed to calculate the variability between sheds, the formula of which is:

$$SSB = \sum n_i \, (\bar{x}_i - \bar{x})^2$$

Where n_i is the number of the values present in that shed, $\bar{x}_i$ is the AV of the shed and $\bar{x}$ is the total AV (of all sheds). With this variability, the variance (ANOVA) is obtained:

$$s_B^2 = \frac{SSB}{degrees\ of\ freedom}$$

and the *SD* is the square root of the variance. Eventually, these s^2_B values were important to obtain the Coefficient of Variation value (*CoV*), whose formula is the following:

$$CoV = \frac{s.d.}{mean}$$

and that was used to get the *SD* value required in SimaPro, by multiplying it for the total quantity of the input entered in SimaPro. Of course, all the calculations were made considering the division of scenarios (PM, DW, CL). Finally, the *SD* value was multiplied by 2 and entered in SimaPro, so the Monte Carlo simulation could be run. In uncertainty analysis there are two types of errors: α (A) and β (B) errors. The A are considered to vary between scenario, the B were the same between the scenario, but were needed for calculating the absolute uncertainty. For example, in the case of feed input, α error could be the amount of feed intake or the number of chicks arrived, while β errors related to production of each feed ingredient. Through these types of errors and differences, the analysis was carried out. Any parameter that was equal between the scenarios returned an identical value, so this type of comparison is based on the differences between the scenarios. As has been said, this kind of calculation was conducted using the SimaPro software, where the LCA model was run 1.000 times, to have a good graphical representation, and during each run, the computer selected a random value for each variable within the uncertainty range of each input. The final model was the ANOVA of all the runs, from which we got different results.

2.4 Results and Discussion

Analysing the farm data, the three different management methods (PM, DW, CL), despite the different amount of birds and sheds consider per cycle, showed values of similar magnitude of electricity for ventilation, for feed augers and for lighting. Similar considerations, can be made for processing load/unload and mill of poultry manure with diesel and heat LPG also. Finally, no significant differences have been noted for clean pine wood shavings inputs and poultry manure also. The inputs considered are per 1 kilogram of broiler live weight (FU), show in Table 2.4.

Type of treatment		**PM**	**DW**	**CL**
Feed consumed	kg	1,905	2,060	1,929
Water used	l	5,218	5,655	4,266
electricity for ventilation	kWh	0,233	0,272	0,218
electricity for feed augers	kWh	0,016	0,019	0,014
electricity for lighting	kWh	0,057	0,093	0,053
clean pine wood shavings	kg	0,123	0,135	0,119
poultry manure	kg	0,410	0,431	0,437
processing load/unload and mill of poultry manure with diesel	l	0,006	0,009	0,005
heat LPG	l	0,060	0,065	0,060
NH_3 in air	kg	0,008	0,005	0,013

Table 2.4: The inputs data for each treatment, per 1 kilogram of broiler live weight (FU).

Instead, most importantly, there was an overall effect of bird performance, especially in the feed consumed per functional unit which different between the treatments, and this affects differences in many impact categories. In feed consumption, the differenti is about 0.1 kg, which means 100 gless to produce the same quantity of meat. In particular, differences in feed consumed are 0.155 kg, 0.131 kg and 0.024 kg per DW towards LM, per DW towards CL, per CL towards LM, respectively. Furthmore, the water used changed, being lower 4.266 L in the management without treatment with microorganisms (C) compared to the two types of treatment (PM and DW) where water consumed is greater than about 1.17 l. As regard the NH_3, this gas is one of the most important in broiler breeding both as a quantity produced and as an effect on the environment. For this reason, it was monitored according to ‘’Experimental Setup Treatments’’. These NH_3 values refer to the number of birds that like for all other inputs, were equally provided for all three scenarios (PM, DW, CL). The results showed that the average amount of NH_3 produced in the CL sheds was higher of about than those treated (PM, DW). In particular, 0,008 kg of NH_3 was produced on the DW sheds, while on the LM sheds an average of 0.005 kg of NH_3 was produced. These values are always in comparison with CL and always refer per 1 kilogram of broiler live weight (FU). The main environmental burdens from each whole treatments (PM, DW, CL) per 1 kilogram of broiler live weight (FU) are listed in Tables 2.5, 2.6, 2.7, 2.8 and 2.9.

Material or activity	**PM**	**DW**	**CL**
Housing emission	0,2272	0,2256	0,1450
Feed + water	2,9600	3,0775	2,9349
Electricity	0,2030	0,2484	0,1995
LPG + diesel	0,1451	0,1515	0,1397
Breeder	0,1786	0,1874	0,1773
Total	3,7139[b] (3,37)	3,8904[a] (7,78)	3,5964[b] (1,06)

Table 2.5: Climate change (kg CO2 e.) for the 3 different treatments considered per 1 kilogram of broiler live weight. ReCiPe method.

[a,b]Different superscripts indicate statistical difference ($P<0,05$) between treatments based only on A uncertainties, which were considered to vary between treatments.

[1]The *SD* (in parantheses) based on A and B uncertainties. The B uncertainties were considered to be similar between the treatments.

Material or activity	**PM**	**DW**	**CL**
Housing emission	0,0097	0,0111	0,0153
Feed + water	0,0292	0,0304	0,0293
Electricity	0,0009	0,0011	0,0009
LPG + diesel	0,0005	0,0005	0,0005
Breeder	0,0048	0,0051	0,0049
Total	0,04515[b] (0,01)	0,0481[a] (0,02)	0,0508[b] (0,01)

Table 2.6: Terrestrial acidification TA (kg SO2 e.) for the 3 different treatments considered per 1 kilogram of broiler live weight. ReCiPe method.

[a,b]Different superscripts indicate statistical difference ($P<0,05$) between treatments based only on A uncertainties, which were considered to vary between treatments.

[1]The *SD* (in parantheses) based on A and B uncertainties. The B uncertainties were considered to be similar between the treatments.

Material or activity	**PM**	**DW**	**CL**
Housing emission	0,0012	0,0014	0,0019
Feed + water	0,0048	0,0050	0,0048
Electricity	0,0003	0,0003	0,0003
LPG + diesel	0,0002	0,0002	0,0002
Breeder	0,0008	0,0009	0,0008
Total	0,0072[b] (0,001)	0,0077[b] (0,003)	0,0079[b] (0,001)

Table 2.7: Particulate matter formation PMF (kg PM10 e.) for the 3 different treatments considered per 1 kilogram of broiler live weight ReCiPe method.

[a,b]Different superscripts indicate statistical difference ($P<0,05$) between treatments based only on A uncertainties, which were considered to vary between treatments.

[1]The *SD* (in parantheses) based on A and B uncertainties. The B uncertainties were considered to be similar between the treatments.

Material or activity	PM	DW	CL
Housing emission	0,0015	0,0017	0,0022
Feed + water	0,0119	0,0125	0,0120
Electricity	0,0001	0,0001	0,0001
Gas + oil	0,0001	0,0001	0,0001
Breeder	0,0012	0,0012	0,0012
Total	0,0147^{b} (0,005)	0,0155^{b} (0,005)	0,0156^{a} (0,014)

Table 2.8: Eutrophication potential (kg PO_4 equivalent) for the 3 different treatments considered per 1 kilogram of broiler live weight. CML-IA method.
^{a,b}Different superscripts indicate statistical difference ($P<0,05$) between treatments based only on A uncertainties, which were considered to vary between treatments.
^{1}The *SD* (in parantheses) based on A and B uncertainties. The B uncertainties were considered to be similar between the treatments.

Material or activity	PM	DW	CL
Housing emission	0,0000	0,0000	0,0000
Feed + water	10,5042	10,9579	10,5844
Electricity	2,3918	2,9272	2,3511
Gas + oil	2,0734	2,1676	1,9957
Breeder	1,4513	1,5234	1,4420
Total	16,4207^{b} (1,91)	17,57614^{a} (2,04)	16,3732^{b} (1,74)

Table 2.9: Non renewable fossil (MJ) for the 3 different treatments considered per 1 kilogram of broiler live weight. CED method.
^{a,b}Different superscripts indicate statistical difference ($P<0,05$) between treatments based only on A uncertainties, which were considered to vary between treatments.
^{1}The *SD* (in parantheses) based on A and B uncertainties. The B uncertainties were considered to be similar between the treatments.

The results show that the PM and DW treatments had lower terrestrial acidification compared with that of CL, and the differences between DW and PM were statistically significant ($P<0.05$). The same considerations can be made for particular matter formation and eutrophication. Instead, regarding climate change, photochemical oxidation and non renewable fossil had significantly higher ($P<0.05$) in PM and DW compared with CL. Table 2.5 to 2.9 also show the breakdown of the environmental impacts by material and energy flow as well as by activity. Although any specific sensitivity analysis was not carried out in this study, these results directly show therelative impacts of the main inputs to the treatments; for example, feed, electricity, gas and oil. Feed caused higher overall environmental impacts than any other materials involved in production; for example 81% and 79% for CL and PM/DW respectively. Water contributed <0,08% average to the feed and water group. Housing emission (in particular NH_3) had the second highest impact (5-22%) followed by electricity (mainly ventilation, feeding, and lighting). Regarding the demand for energy (CED), calculated as non-renewable fossil, the first contribution comes from feed and its production with an average value of 63 MJ, followed by the ventilation with an average value of 11 MJ. There are no significant differences between treatments (PM, DW, CL). The Table 2.10 show three categories of environmental impact appear to be advantageous in the treatment with microorganisms, (PM and DW) compared to untreated (CL).

Impact category		**PM**	**DW**
Climate change	kg CO_2 e.	3,2666	8,1746
Terrestrial acidification	kg SO_2 e.	-11,0573	-4,8768
Particulate matter formation	kg PM10 e.	-9,0761	-2,7274
Photochemical oxidation	kg C_2H_4 e.	2,7799	9,6818
Eutrophication	kg PO_4^{---} e.	-5,2125	-0,1011
Cumulative Energy Demand	MJ	0,2909	7,3471

Table 2.10: Comparison in % of the two treatments (PM and DW) compared to CL.

In particular, for terrestrial acidification, the PM can have an environmental impact of about 11% less than CL and an avoided impact of about 5% for DW. Furthore, significant were the environmental impact avoided of PM and DW compare to CL regarding photochemical oxidation. Precisely, the avoided impact is about 9% for PM and about 3% for DW. Finally, compared with eutrophication, the impacts avoided for the PM are about 5%, while DW are not more significant (about 0.1%). The interest of this type of studies is increasing, considering different aims, inputs and outputs, for the contribution on the environmental impacts such as resources use and climate change. There are many fields of application in different countries, from the crop production to animal farm, including studies about pigs, turkeys and broilers. However, it is interesting that there are no other LCAs that analyze the emission of ammonia in the same farm, comparing different treatments with strains of microorganism. About broilers, there are some different studies to compare to this one, they all analyzed the LCA of broilers production, but they had different aims. In United Kingdom, there was a study about the comparison of three different types of raising and the impacts connected, in order to identify how to reduce them (Leinonen I., et al., 2012). The three systems were standard indoor, free range and organic and the results showed how the single inputs, like number of bird or feed consumption, changed in each one and so also their environmental burdens. As our study, this study confirmed the high impact of feed production in broiler raising (Table 2.11).

	United Kingdom			Italy		
	standard	free range	organic	CL	PM	DW
feed + water	3,14	3,69	4,08	2,94	2,89	2,72
electricity	0,16	0,15	0,17	0,07	0,06	0,07
LPG + diesel	0,43	0,34	0,31	0,07	0,07	0,07
total	4,41	5,13	5,66	3,44	3,38	3,21

Table 2.11. Climate change (kg CO_2 eq) for the six different system compared: three in UK, modified FU from 1000 kg of expected edible carcass to FU 1 kilogram of broiler live weigh;, and three in Italy, considered per 1 kilogram of broiler live weight.

The strong contribution of feed production was visible also in another study, in the same country, but with different production system and aim: it was the analysis of environmental impact of egg production systems (Leinonen I., 2012). Here, the comparison was between 4 hen-egg production systems (cage, barn, free range and organic). The production of feed showed the highest values in all impact categories considered, while lower proportions of impacts originated from farm electricity use, like in our study. However, the performances and the results came from different systems and types of management, so the results of these studies showed only that a similarity between different reality could exist and they couldn’t be considered as an average of all production systems. Another interesting study was about the comparison of broiler production to that of pork and beef (Gonzalez-Garcia S., et al., 2013), made in Portugal. They first identified the environmental burdens of a chicken farm, studying all the production stages from feed production to slaughterhouse, then the researchers compared their study with others about broiler and different animal production. As in our study, the feed production results in the main responsibility of environmental damages, while heat production was the factor that less contributed to the impact. About the comparison of different species, the idea was to compare the greenhouse gas emissions of different farming systems of pork, beef and broiler, considering identical system boundaries. The results showed that broiler production presented the lowest impact, in particular in terrestrial acidification and eutrophication, although lower turns out climate change also. These different studies show how it is possible to study a single farm in order to understand its environmental burdens or study a comparison between different management systems and types of breeding or animal production, to quantify the impact and understand which parts of the production chain show the higher contribution. Broiler is the most consumed meat in Italy and in general in the world and a lot of LCAs were published, but before the current study, none was made in order to investigate the use of microorganism involved in particular in the nitrogen cycle. In this study, a farm situated in North of Italy was investigate in detail to evaluate the environmental impact and compare three different types of management (PM, DW and CL) of intensive broiler production system. Feed production, including all processes from the crops used as raw material to the processing for the creation of the feeds, was the main input that contributed in environmental impact, as already ensured in previous studies. Moreover, this study had the aim to compare the different managements using microorganisms with uncertainty analysis applying Monte Carlo simulations, and effective differences in emission of ammonia to air were found. In fact the management with DW produced the lowest results in all the impact categories considered, and also showed the lowest value of NH_3 emission per 1 kilogram of broiler live weight. For example, in the category of Climate Change it showed less emissions in 77% of the Monte Carlo model simulations, compared to the management CL, and in 69%of the simulations compared to the PM. In Terrestrial Acidification, DW was better in 81% of the simulations than CL and in 74% of the simulations when compared to the PM. Finally, concerning the environmental impact, it can be suggested that in the intensive system of broiler production, a management where there is a treatment with these kind of microorganisms made through the PM and DW would be beneficial, but more researches are needed, in order to understand the effect of this treatment outside the breeding (use of the exhausted poultry manure).

CHAPTER III

ENVIRONMENTAL PERFORMANCES OF DIFFERENT USE OF POULTRY MANURE WITH AN LCA APPROACH, THE NORTH-EAST ITALIAN CASE STUDY

3.1 Introduction

With respect to meat production in Italy, poultry meat production is among the main ones with a production of 1.25 million tonnes, 68% of which is broiler meat (Avec, 2015). Most of the broiler meat come from standard indoor system farms and they are located in the North-East regions (Unaitalia, 2014), often concentrated in specific areas, that often leads to criticism due to emissions, in particular ammonia (NH_3), nitrogen oxides (N_2O) and methane (CH_4) produced and the difficulty to obtain a proper disposal of poultry manure. This is because the broiler farms in this area are a lot and all are characterized by the absence of field where the poultry manure could be spread. The broiler indoor system is characterized by a standard production chain, which starts with the animal feed production and chick hatching, proceeds with breeding and closes with the slaughtering, packaging and distribution of the finished product. However, the poultry chain has never given much importance to the co-product that inevitably forms, that is, the poultry litter. The poultry litter co-product, has excellent amounts of nitrogen and phosphorus (Chamblee and Todd, 2002), but also a good heating value of about 7 MJ kg^{-1}. The intensive indoor breeding and the usual poultry manure spreading in arable soils lead to heavy water eutrophication and high atmospheric pollution with the consequent environmental impacts. A proper management of the poultry manure is highly recommended by the European Union with the Nitrate Directive (European Union 1991), that limits the spreading rate of animal manure and with the electricity production from renewable sources directive (European Union 2001), that fosters an internal supply of energy market and a saving emissions of greenhouse gases (Taylor 2008; Kim and Dale 2004). All biomass is called climate neutral, as it releases carbon to the atmosphere that was photosynthesized in the latest past (Reijnders and Huijbregts 2007). The special interest to these resources is motivated by the high energy price, the independence of source supply, the substitution of fossil fuels, the favorable Global Climate Change outcome and the economic chance for rural areas. Poultry manure may be altogether oriented to organic fertilizer production or in alternative to renewable energy source. Potentially, poultry manure can be recycled into energy and energy carriers, or upgraded its nutrients and carbonic matter as agronomic organic fertiliser. Often poultry manure is used as fertiliser because is an important source of nutrients. It may be applied directly on arable land, if the transport distance is not excessive, or composted, to produce a stable and odourless biofertiliser, or pelletised, if were available a cheaply drying process, to produce an organic fertiliser can be sold in far agricultural markets with high demand of fertilisers. Furthermore, poultry manure can be recycled as energy by combustion in a power plant to produce heat or heat and electricity. Either processes produce ash that contain residual non-volatile nutrients. While, biogas production by anaerobic digestion is not an efficient technology for poultry manure.

3.2 Aim of the work

The aim of the current study was to evaluate the environmental impacts of broiler production associated to two different treatments of poultry manure and its end use as agronomic fertiliser (Figure 3.1).

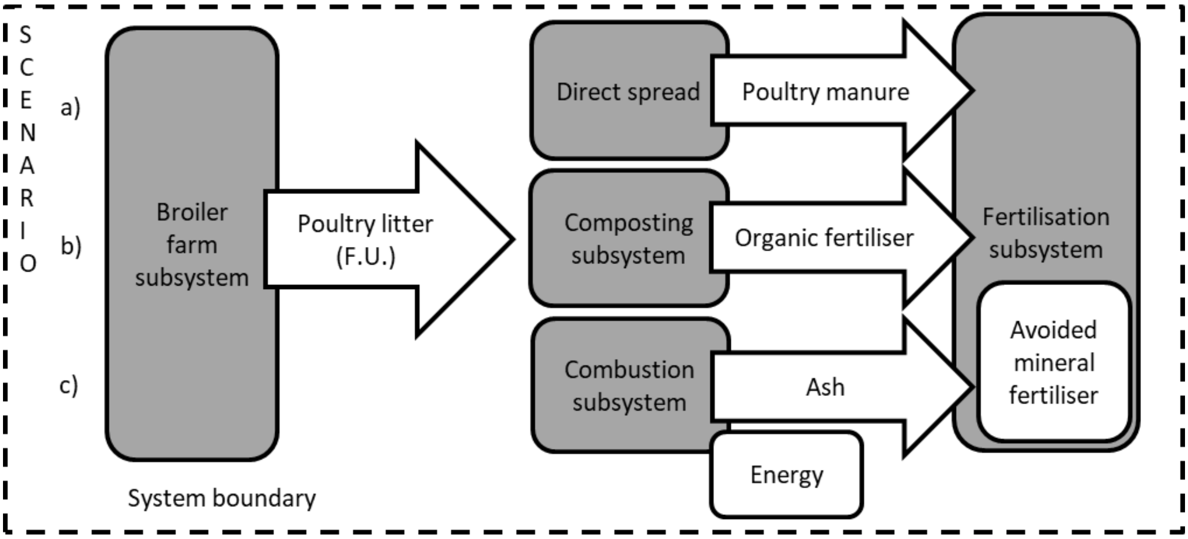


Figure 3.1: System boundaries of two different treatments of poultry manure and its end use as agronomic fertiliser.

The two treatments analyzed are: production of organic fertilizers (composting) POF subsystem, where poultry manure turns into a handy and transportable organic fertiliser and direct combustion CP subsystem, where poultry manure being used as a renewable energy source includes the production of heat and electricity, by combined heat and power plant (CHP), and residual ash. The choice of CP was made to remain closest to the situation used by the British. This is for a comparison of data, but because for now it is the situation most used in Italy also. After all were considered the environmental impacts of the end use by a fertilization subsystem that consists into the spreading on arable soil of three types of products: a) poultry manure, where no treatment was carried out, b) organic fertiliser, achieved by POF and c) ash, from CP waste. A comparative Life Cycle Assessment of poultry manure potential use was accomplished through three scenarios:

a) the traditional poultry manure direct spreading DFS,

b) a organic fertiliser use POF and

c) renewable energy source CP.

3.3 Methodology

LCA approach is defined as a methodology for the holistic assessment of the impact that a product or service has on the environment throughout its life cycle (from extraction of raw materials, through manufacturing, logistics and use to recycling, if any, or disposal) “from cradle to grave” analysis (ISO 14040, 2006).

3.3.1 Goal and Scope definition

This study is mainly focused on the utilization of poultry manure as organic fertiliser, by POF, and as renewable energy source, by CP, instead of the traditional spreading of manure in arable soils DFS. Concerned the CP, it was not to compare different methods of combustion, but compare CP with POF and DFS. LCA has tried to evaluate different methods of treatment/valorization of poultry manure, comparing it with a base scenario that is DFS. Therefore, the goal was to compare these scenarios, excluding from the boundaries of the system, the agronomic area (arable land, crops, etc.). Although the main assumptions are based on North-East Italian conditions, regarding breeding and poultry manure management, the study is not restricted to Italy, and it can be applied to other countries. Moreover, it is significant to observe that electricity requirements are taken from the Italian national grid which affects the results. Therefore, the aims of this study were to evaluate the environmental impacts of broiler farm, of the two poultry manure treatments (POF and CP) and a common fertilization end use. Then they are compared with the conventional fertilization system DFS. Moreover, the hot spots all over the life cycle were identified, and actions were suggested for environmental development.

3.3.2 Functional unit

In this study, two different final products have been managed, energy and organic fertiliser, taking into account the different choices formulated. Concerning the alternative utilizations of poultry manure and not being able to compare two functional units, 1000 kg of broiler manure ready to be treated was the functional unit (FU) for both systems studied. The LCA system model used in the analyses was developed originally at Cranfield University (Williams et al. 2006, 2016) and subsequently developed further in a partnership with University of Padova (Guercini and Sgorlon, 2016, unpublished data) and Scotland's Rural College, Edinburgh (Leinonen et al. 2012, 2016).

3.3.3 Allocation and system expansion

Allocation is one of the most critical subjects in LCA studies. A choice is required for multi-output systems that produce more than one co-product can have a strong effect on the results. Several authors who have analyzed the energy production from manure prefer an allocation on the basis on energetic inputs (Uhlin, 1993) or outputs (Reijnders, 2005), while many authors do not consider the need of an allocation based on monetary value since broiler and poultry manure have high different economic value (Gonzales-Garcia, 2014). Broiler, in the poultry chain, often is the only economic product, while the manure not provide any income, often has a negative monetary value. In his study Reijnders (2005) argues that when monetary value is negative will lead to a negative LCA, which in case of the global warming potentials correspond to a CO_2 net sequestration. This interpretation can be extended even when manure have not commercial value will result to a null impact assessments. Due to these considerations and the dual utilization as fertilizer and energetic power, in this study a system expansion procedure was performed. Considering the fertilizer potential of manure and organic fertilizers, in the inventory data was avoided the impacts of the equivalent amount of mineral fertilizers, while the impacts of heat production by natural gas and of Italian electricity production were withdrawn in the CP subsystem.

3.3.4 System boundaries

Figure 3.1 shows all the subsystems involved in each alternative under assessment included in the system boundaries. The upstream of the whole system is the common broiler farm subsystem where poultry manure is produced. The poultry manure can be treated or not, it will be spread directly on the field DFS as in traditionally way. In the case of treated poultry manure, two alternatives are proposed: POF and CP, in the first case a organic fertilizer will be produced, while in the second one thermal and electrical energy and residue ash. Even in this case organic fertilizer and ash will be used in the fertilization subsystem.

3.3.5 Broiler farm subsystem

Processes carried out in this subsystem (Figure 3.2) begin with the hatching and the transport of chicks at the farm, where they stay for an average breeding period of 55 days.

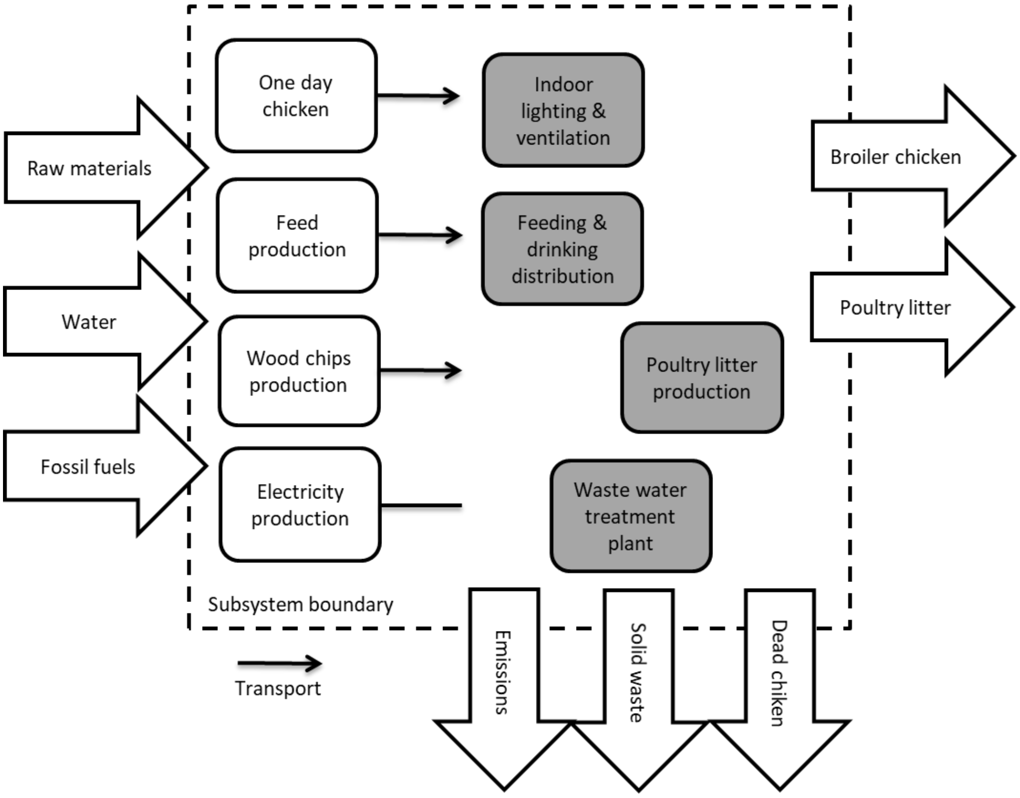


Figure 3.2: System boundaries of broiler farm.

Broilers live on a bedding, which is composed by spruce or pine chips free of pollutants and of fine dust providing a health environment. Poultry bed spreading and reaping were considered within the broiler farm subsystem boundaries. Every broiler of average 3.4 kg final weight was fed with average 6.2 kg of FCR. The feed is mainly composed by maize, wheat, soybean, soybean oil, monocalcium phosphate, protein concentrate and fats. Chicken feed is the main factor responsible for environmental impacts (Castanheira et al., 2010; Hospido et al., 2003). Feed production involves the cultivation of different raw materials which are harvested and stored separately then are floured, mixed, granulated and disinfected before stored and delivered to the farm. Production, transport, storage and distribution of chicken feed were included within the subsystem boundaries. Every chicken drinks average 200 litres of water taken from shaft. A cut off criteria was operated on pharmaceuticals, chemicals, detergents and disinfectants, because the amount aren’t significant of the whole environmental profile (Castanheira et al., 2010; Hospido et al., 2003). Wastewater come from cleaning activities is treated in an owner wastewater treatment plant (WWTP), which was included within the subsystem boundaries. Capital goods and infrastructure were not included within the subsystem boundaries also.

3.3.6 Production of organic fertilizers (POF) subsystem

POF is an aerobic degradation of poultry manure. In North-East area of Italy, usually total period is of 90 days of which 30 days of the high rate temperature stage and 60 days of curing phase. At the end of this period it will get a stabilised compost odourless, pathogen free, fine texture and quite dry. This process involves some disadvantages such as loss of ammonia (NH_3) and other nutrients due to a low C/N ratio (Gray et al., 1971), the use of capital goods, infrastructure, worker cost and agriculture land occupation (Sweeten, 1988). Moisture content influences composting rate. A moisture range between 40% and 60% is optimal to start the process, while higher and lower content inhibit it to stall the development. In fact a high content produces an anaerobic and anoxic environment while a low hampers the enzymatic activity of bacteria and microorganism. Heat generated during POF, sludge leaching and forced aeration cause evaporation then the moisture content should be maintained to the optimal condition. Figure 3.3 illustrates all the processes involved in composting subsystem.

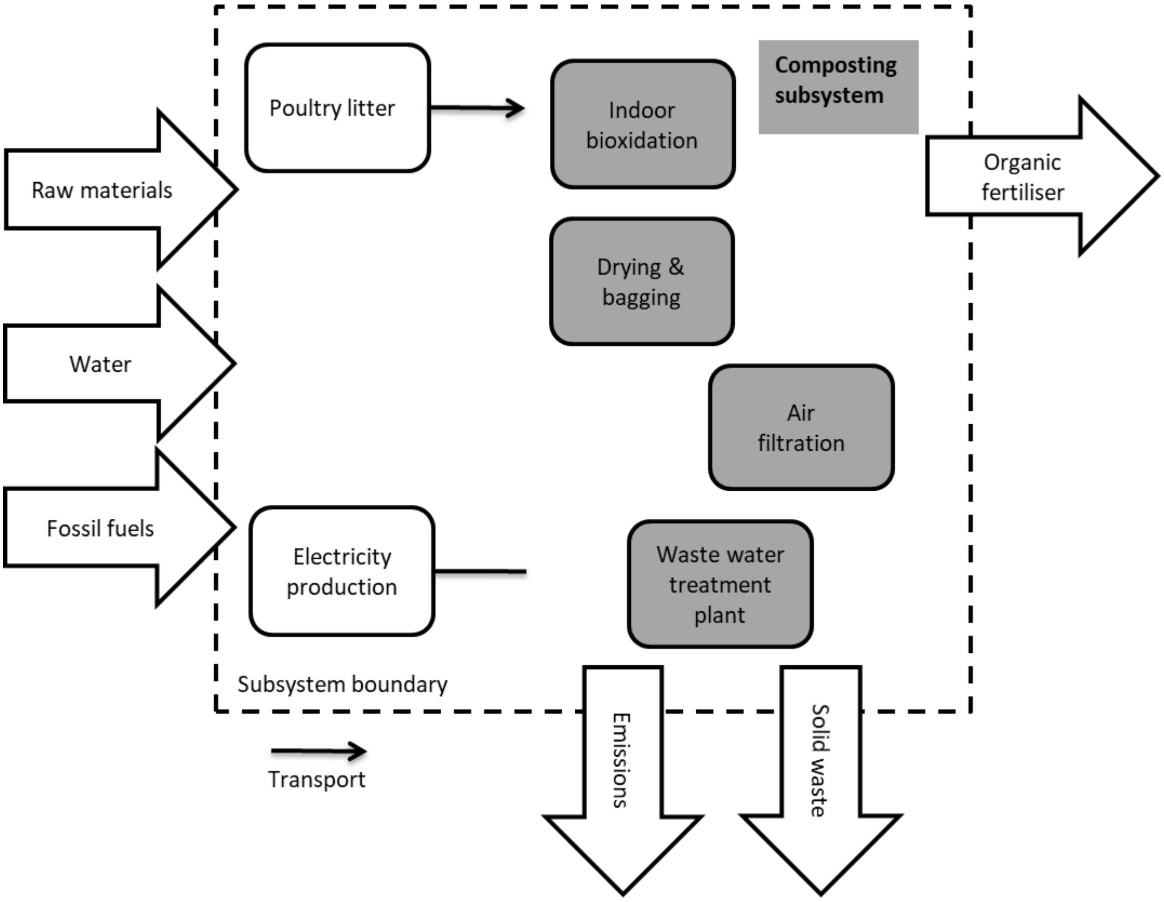


Figure 3.3: System boundaries of production of organic fertilizers (POF) plant.

Processes carried out in this subsystem begin with the transport of poultry manure at the farm by lorries, after they were discharged, are cleaned and sanitised. Poultry manure is laid out by a wheel loader on a concrete platform to shape a long heap 8 m wide and 1.5 m tall. During curing phase, one time a day, the wheel loader turns and aerates all the compost. It grinds the coarser material and reduces it to an average size of 15 mm from the initially muddy texture of poultry manure. The formation of small particles increases degradation due to the larger surface area available to microbes and enhances the porosity for oxygen exchanges. The building structure consists of a concrete barn with airtight systems to allow the air aspiration and the exhaust air treatment by a biofilter. When stabilized, compost is sifted, dried, bagged and labeled.

3.3.7 Combustion (CP) subsystem

The CP of poultry manure provides combined generation of heat and electrical power. The subsystem has an efficient combustion, gas stay more than 2 seconds at 850 - 950 °C of temperature in a highly oxidative combustor. The combustor function is to achieve the total and perfect combustion of the effluent by exhausting the processes of oxidation of the unburnt gas and the demolition of the complex molecules. Thus, playing an indispensable role in the reduction of polluting emissions into the atmosphere. Then, gas yield their enthalpy to the diathermic oil recovery system raising its temperature up 300 °C. The warm diathermic oil arrives to the Organic Rankine Cycle system to produce electric energy. Flue gas are treated by a catalyst in which NH_3 is sprayed and nitrogen oxides (NO_2) are reduced into N_2, and by a cyclone and a bag house filter that removes dust to less than 10 mg/Nm^{-3}. Poultry manure caloric value, that is the quantity of energy released by each unit of combustible mass, increases linearly with decreasing moisture content, that in the operative line must be lower than 45%. Low ash fusion temperature of poultry manure might cause problems when using fixed bed combustion system, for this reason it is used plant with inclining grates. The burning produces fly and bottom ash also, which keep most of the phosphate and potash present in the poultry litter, while the nitrogen is lost into the gas as NO_2. For the residual nutrient content, ash is stable and sterile fertilizer, but does not provide any organic matter.

Figure 3.4 illustrates all the processes involved in combustion subsystem.

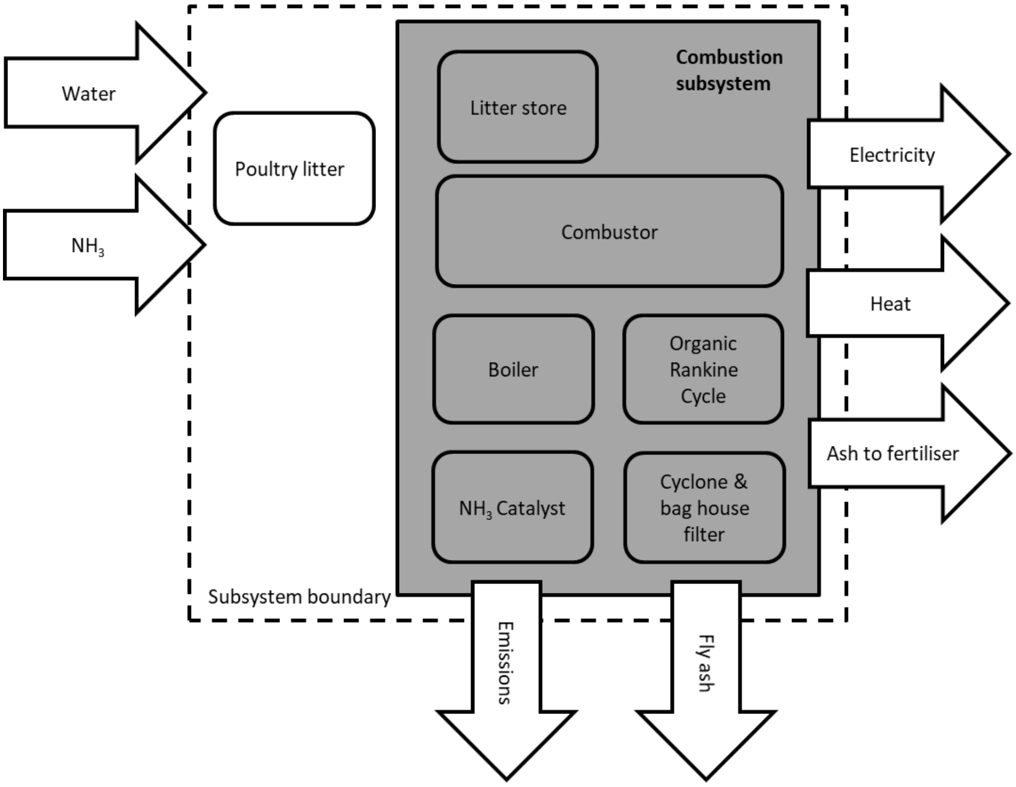


Figure 3.4: System boundaries of combustion (CP) plant.

The process is carried out within the broiler farm, so no transport needs, where there is an accumulation and pretreatment area. The combustion plant has a thermal potential source of 1630 kW and management is fully automated.

3.3.8 Fertilisation (DFS) subsystem

Manure, organic fertiliser and ash, as has been said, have a nutritional capacity of N, P_2O_5 and K_2O and an amendment function to the high C content in poultry manure and organic fertiliser. Once they have spread on the field, these components remain in the soil to the crop or are lost. The amounts of potentially absorbable nutrients by crops are counted to one of the three fertilizers (poultry manure, organic fertiliser and ash) which compensates the production of the spared mineral fertilizer for each type of fertilization (Leinonen et al., 2012). To assess the emissions of three types of fertilizations DNDC model was used. The DeNitrification-DeComposition (DNDC, 2000) is a process-base model of carbon (C) and nitrogen (N) biogeochemistry in agricultural ecosystems, consists of two components. The first, regarding of the soil climate, crop growth and decomposition sub-models, predicts soil temperature, moisture, pH, redox potential (Eh) and substrate concentration profiles driven by ecological drivers. The second component, consisting of the nitrification, denitrification and fermentation sub-models, predicts emissions of carbon dioxide (CO_2), methane (CH_4), ammonia (NH_3), nitric oxide (NO_x), nitrous oxide (N_2O) and dinitrogen (N_2) from the plant-soil systems. The place of study considered is the area of Mira, which has characteristics that represent a typical situation in North East of Italy. This area is the same of the broiler farm and of the treatments of poultry litter. The direct spread of poultry manure was taken as basic scenario and it was compared to the organic fertilizer and the ash. Furthermore, the Mira area was chosen also because confident data were to be included in the DNDC model, about the soil (Dafnae, 2016) and meteorological data (ARPAV, 2016). To represent the DNDC model realistically, a three-year rotation of wheat-soybean-corn were considered. This type of rotation and crop choices represent the main crops cultivated and the main broiler feed also. To evaluate effects of the application of poultry manure or organic fertilizer or ash for a long time, following the IPCC 2006 guideline, was decided to simulate this rotation for 100 years and the annual average was considered.

3.3.9 Inventory analysis

Inventory data collection in order to fulfill the Life Cycle Inventory (LCI) is the great deal of effort into the LCA projects. Data used in this paper were collected from different sources and in many different ways: field data, research reports, technical manuals, and literature. LCI data for all subsystems were provided by visits in broiler and compost farms, through interviews to technical experts and estimations. All the primary data corresponded to 2016-2017 years. Background information from broiler breeding was obtained from field data of Nord East Italian producers association livestock dedicated to meat production (Sgorlon et al. 2017). Table 3.1 lists all inventory data of broiler farm subsystem management for the major operations collected for two years.

Inputs		
Water	11492	kg
1 day chicken	736	p
Feed	4552	kg
Transports	96	km
Wood chips	291	kg
Electricity	727	kWh
Liquified Petroleum gas	143	l
Diesel	14	l
Outputs		
Manure	1000	kg
Broiler	2433	kg
Emissions		
Particulates <10 µm		kg
NH_3	11,943	kg
CH_4	7,009	kg
N_2O	0,976	kg

Table 3.1: Inventory data of broiler farm subsystem management.

The production of the typical broiler farm was more of 2000 ton per 640000 broilers per each cycle. Feed production and composition was studied and inventoried in detail. Background data concerning the production of feed ingredients, one-day chicken, wood chips and bed materials, their transport, electricity and fuel required in this subsystem was obtained from the Ecoinvent database (Dones et al. 2007; Nemecek et al. 2007, Werner et al. 2007). Inventory data (Table 3.2) regarding the operation of composting was provided by a company that manages 50.000 ton of poultry manure per year.

Inputs		
Manure	1000	kg
Water	32	kg
Transport	50	km
Electricity	77	kWh
Gas	23	m^3
Outputs		
Organic fertilizers	452,7	kg
Emissions		
H_2O	502,303	kg
NH_3	1,93	kg
NOx	1,44	kg
CO_2	41,13	kg
CH_4	0,8	kg

Table 3.2: Inventory of the operation of production of organic fertilizers (POF) was provided by a company that manages 50.000 ton of poultry manure per year.

It has the capacity to treat poultry manure comes from 10 broiler farms. Inventory data related to the production of electricity and fuel for drying was taken from the Ecoinvent database (Dones et al. 2007). Transport required to supply poultry manure to the production line were also taken into account, lorries were used as transport mode and the mean distance was 50 km. Combustion subsystem was modeled to poultry litter composition with a technology biomass treatment capacity of 4500 ton per year, necessary to satisfy the poultry manure production of one average broiler farm. Table 3.3 shows the specific LCI data for the combustion subsystem.

Inputs		
Manure	1000	kg
Lubrificating oil	0,044	kg
Soda	3,126	kg
Urea	2,151	kg
Water	10,56	kg
Outputs		
Electricity	236	kWh
Heat	873	kWh
Ash	85	kg
Fly ash	15	kg
Emissions		
CO_2	681,65	kg
NH_3	0,197	kg
NOx	0,718	kg
N_2O	0,282	kg
CO	1	
Particulates <10 µm	0,05	kg
P	0,027	
SO_2	0,75	kg

Table 3.3: Inventory of the operation of direct combustion (CP) plant.

The net efficiency of electric and heat productions, combustion emissions, consumables data were provided by boiler producer and processed by the Ecoinvent database (Dones et al. 2007). Electric and heat amounts were considered as credits for the avoided burdens of heat production by natural gas and of Italian electricity production. Table 3.4 shows the specific LCI data for the fertilization subsystem.

Fertiliser:	**poultry manure**		**organic fertiliser**		**ash**	
Inputs						
Transport	35	km	70	km	5	km
Fertiliser spreading	1000	kg	453	kg	85	kg
Avoided products:						
Ammonium nitrate	112,9	kg	66,0	kg	-	
Superphosphate	137,2	kg	21,9	kg	20,8	kg
Potassium chloride	50	kg	73,3	kg	24,3	kg
Outputs						
Water emissions:						
NO_3^-	40,460	kg	77,580	kg	16,430	kg
N_2	0,001	kg	0,001	kg	-	
Air emissions:						
CH_4	-0,410	kg	-0,278	kg	-0,010	kg
NH_3	0,370	kg	0,091	kg	0,018	kg
NO_2	24,050	kg	19,570	kg	2,610	kg
NO	1,940	kg	1,910	kg	0,250	kg
N_2	53,900	kg	68,640	kg	12,650	kg

Table 3.4: Inventory of the fertilization subsystem.

It involves the transport of the fertilizer, its spreading, the water and the air emissions and, according the avoided loads method, the equivalent amount of spared mineral fertilizers. Ammonium nitrate, triple superphosphate and potassium sulphate production processes was taken from the ecoinvent database (Althaus et al., 2007). For the three scenarios, it was assumed that ash is used within the same agricultural farm, while poultry manure is carried out in a neighbor area near the poultry farm, and the organic fertiliser is moved outside the territory toward agricultural markets need organic fertilisers. Water and air emissions were obtained by the DNDC model. Data entered for Mira area (45° latitude N) were: daily maximum and minimum air temperatures, daily precipitation, wind speed, solar radiation and relative humidity. Furthermore, was considered the N concentration in rainfall (2 mg N l^{-1}), atmospheric background NH_3 concentration (0.06 μg N m^{-3})

atmospheric background CO_2 concentration (380 ppm) and annual increase rate of atmospheric CO_2 concentration (0 ppm yr^{-1}) (ARPAV, 2000). Regarding the soil characteristics, were considered the following parameters: crop field land-use, sandy loam soil texture (0.09), bulk density (1.6 g cm^{-3}), soil pH (7.63), clay content (0.1234), field capacity (0.55), wilting point (0.15), hydro-conductivity (0.1248 m hr^{-1}) and porosity (0.4). Furthermore, the content of total soil organic carbon (SOC), including litter residue, microbes, humads, and passive humus at surface layer (0-5 cm) was 0.00805. The depth of top soil with uniform SOC content was 0.2 m, the SOC decrease rate below top soil (0.5 – 5.0) was 2, the initial NO_3^- concentration at surface soil was 4.025 mg N kg^{-1} and the initial NH_4^+ concentration at surface soil was 0.805 mg N kg^{-1}. Table 3.5 reports the main values used.

Products	**NTK**	**C/N**	**OC**	**K_2O**	**P_2O_5**
A - poultry manure	% tq		% tq	%tq	%tq
average value	**4,0**	10,5	41,4	3,0	2,9
dev.st	2,0	1,2	6,6	0,2	0,2
CV (%)	50,3	11,3	16,0	7,7	7,7
B - organic fertiliser	%ss		% tq	%tq	%tq
average value	**5,1**	6,9	37,3	2,9	3,4
dev.st	0,5	1,2	x	1,1	0,7
CV (%)	12,3	15,1	x	31,1	20,5
C - ash	%ss		% tq	%tq	%tq
average value	**0,1**	x	x	14,7	6,0

Table 3.5: NTK (total N), OC (organic carbon), K_2O (potassium), P_2O_5 (phosphorus).

A) *Direct spread of poultry manure*. For the wheat and the corn crops, 1000 kg of poultry manure were counted for amount of 413.9 kg C ha^{-1} and 39.5 kg N ha^{-1} respectively. While soybean crop, following cultivation practices, did not used poultry manure.

B) *Spread of organic fertiliser*. Only for the wheat and the corn crops, 500 kg of organic fertiliser were counted for amount of 186.5 kg C ha^{-1} and 27.02 kg N ha^{-1} respectively, not for soybean crop, following the considerations made.

C) *Spread of ash*. Nitrogen and carbon content is almost absent in ash, so considered this scenario as if nothing spread. The phosphorus and potassium values for all fertilisations have been considered as avoid products compared to mineral fertilizers.

3.3.10 Environmental impact categories

Concerning the impact assessment phases defined by the LCA methodology, only classification and characterization stages were considered, while normalization and evaluation were avoided, since they would not provide additional information according to the goal and scope of the study.

Emissions and extracted resources of the inventory results were classified into the following potential impact categories:

1) Global Warming (GWP) is related to the greenhouse gas emissions and is expressed by a 100 years timescale (IPPC, 2013). This indicator is very important in this research, to define if poultry litter may meet the conditions set out for a renewable biomass material.

2) Acidification (AP) includes substances with a wide range of impact on atmosphere, soil, surface and ground water and their organisms and ecosystems. Animal production contributes to acidification due to the use of litter as fertilizer.

3) Eutrophication (EP) includes all effects due to excessive emissions of macronutrients in the environment above all to soil. Once again, poultry manure has a strong impact through the use as fertiliser being rich in nitrogen and phosphorus as well as due to the runoff of these components to waters.

4) Photochemical Oxidation (PO) is the formation of reactive chemical compounds by the action of ultraviolet light on Volatile Organic Compounds (VOCs) and Carbon monoxide (CO) in presence of Nitrogen oxides (NO_x). The different use of poultry manure as fertiliser or as combustible contributes to PO through a large amount of VOCs emissions in the first case, of CO in the second one.

5) Fine Particulate Matter with a diameter of less than 10 µm (PM_{10}) causes respiratory problems. They are formed by organic and inorganic substances and by emissions in air of sulfur dioxide (SO_2), ammonia (NH_3), and nitrogen oxides (NO_x). The fine dust in the broiler farm, the spreading in the fertilization and the combustion smoke concur to increase the PM_{10} formation.

6) Fossil fuels depletion (FD) is strongly dependent on used forms of electricity generation, that in this case study is the Italian one. It is usually linked with the consumption of natural resources, but the use of waste management, like poultry litter, on the other hand could be as well as a significant means of conserving natural resources. Combining both subsystems in fossil fuels depletion terms would be interesting.

7) Cumulative Energy Demand (CED) of a product represents the direct and indirect energy consumed during throughout the life cycle, including the extraction, manufacturing, and disposal of materials used to produce it. CED can be determinate by different concepts, one may distinguish between energy requirements of renewable and nonrenewable resources (Frischknecht 2007). In this study the nonrenewable cumulative energy demand, represents more than 95% of the total energy used.

The potential impact categories analyzed are very related with impacts derived from broiler farm management due to CH_4, NH_3, NO_3^- and N_2O derived from manure production, handling and disposal scenarios. Furthermore, these impact categories are the most widely used in the animal production environmental studies (Beauchemin et al., 2010; Cedeberg and Stadig, 2003; Reckman et al., 2012), which can facilitate the comparison of results from different researches. In the last years several characterization methods for the impact assessment were proposed. To better comprehension, two methods were used: CML-IA, 2013 version, (Guinée et al. 2002) and the successor ReCiPe (Goedkoop 2009), at midpoint level and hierarchist perspective both. EP, AP and PO categories were assessed by two methods, PM10 by ReCiPe method and FD by CML one. GWP and CED are two widely used indicators for environmental impacts suggested by IPPC (IPPC, 2013) and Ecoinvent (Hischier and al., 2009).

3.4 Results and Discussion

Table 3.6 summarizes the LCA characterization results for three scenarios:

a) the traditional poultry manure,

b) the organic fertiliser use and

c) the renewable energy source.

Values of b) and c) scenarios are showed in relation to a).

Impact category	Method	Unit	poultry manure	organic fertiliser	renewable energy source
Global warming (GWP100a)	IPCC	kg CO_2 eq	8429	3,5%	1,6%
Eutrophication	CML	kg PO_4^{---} eq	65,3	16,2%	-33,3%
Acidification	CML	kg SO_2 eq	90,7	2,5%	-9,7%
Photochemical oxidation	CML	kg C_2H_4 eq	1,68	-5,2%	-27,7%
Particulate matter formation	ReCiPe	kg PM10 eq	23,5	1,0%	-18,0%
Abiotic depletion (fossil fuels)	CML	MJ	11062	5,4%	-9,5%
Total CED	CED	MJ	46025	8,1%	4,9%

Table 3.6: LCA results per 1000 kg of poultry manure for three scenarios (unit amount for traditional poultry manure scenario and percentage difference for organic fertiliser and renewable energy source).

According to these results, a reduction in the environmental loads was possible in almost all impact categories selected when poultry manure is treated as renewable energy source. An important improvement has been achieved in photochemical oxidation (PO) and eutrophication (EP) when manure is combusted with a decrease of 27.7% and 33.3% respectively according to CML method. Other impact categories to point out are: acidification (AP), abiotic depletion of fossil fuels (FD) and particulate matter formation (PMF), with a diminution of about 10% for the first two categories and 18% for the last one. These results come from strong reduction of NH_3, CH_4 and VOCs emissions during outdoor storage and field spreading (Bengtsson and Seddon, 2013; Katajajuuri, 2007; Williams et al., 2006). The most important effect on decreasing fossil fuels depletion is from the substitution of natural gas for electricity and heat production. A small worsening has been registered in global warming potential and cumulative energy demand, 2% and 5% respectively, when poultry litter is combusted. These phenomena, apparently in contrast to the previous results, can be explained by the higher lifetime organic matter content in the arable soil and by the reduction in energy demand for mineral fertilizer production when using the direct spreading of poultry manure. Regard to the higher value of the CED, in renewable energy source scenario, it must be considered that this impact category considers also the energy required for the operation of the power plant and heat generation. When poultry manure scenario is substituted by organic fertiliser manufacturing seems to present an increasing in the environmental burdens in almost all impact categories. According to the results (Table 3.6), the transformation of broiler litter in organic fertiliser is likely to be the worse option in environmental impacts in comparison with poultry manure or renewable energy source. Increments in environmental loads at any impact category are mainly due to emissions derived from the organic fertiliser utilization, mostly in EP category (+16%), as well as FD (+5%) and CED (+8%) due to the high energy request. A small worsening has been registered in PMF (+1%) and AP and GWP with about +3%. An improvement has been achieved only in photochemical oxidation impact category with a decrease of 5% respect to poultry manure. Table 3.7 shows the contributions to each impact category for the subsystems involved in three scenarios.

		poultry manure		organic fertiliser			renewable energy source		
Impact category	Unit	broiler farm	fertilization	broiler farm	composting	fertilization	broiler farm	combustion	fertilization
Global warming (GWP100a)	kg CO2 eq	103,7%	-3,7%	100,1%	2,0%	-2,1%	101,9%	-2,2%	0,3%
Eutrophication	kg PO4--- eq	**55,5%**	44,5%	**47,8%**	1,3%	50,9%	**83,2%**	-0,1%	16,8%
Acidification	kg SO2 eq	87,6%	12,4%	85,5%	4,7%	9,8%	97,0%	1,2%	1,8%
Photochemical oxidation	kg C2H4 eq	**61,2%**	38,8%	**64,6%**	1,8%	33,6%	**80,0%**	8,5%	11,5%
Particulate matter formation	kg PM10 eq	78,4%	21,6%	77,6%	4,9%	17,4%	95,5%	1,4%	3,1%
Abiotic depletion (fossil fuels)	MJ	99,5%	0,5%	94,4%	5,4%	0,2%	104,7%	-9,5%	4,8%
Total CED	MJ	105,9%	-5,9%	98,0%	5,0%	-3,0%	101,0%	-1,2%	0,3%

Table 3.7: Contributions of subsytems to the impact categories for poultry manure (DFS), organic fertiliser (POF) and renewable energy source (CP) scenarios.

According to results the main contributor to almost all the categories was the broiler farm subsystem, which involves the feed process and the emission activities related to the production of the meat. Broiler farm subsystem represents more than 80% of the environmental loads for the renewable energy source scenario, while more than 75% for the first two scenarios except for EP and PO which fertilization subsystem correspond to about 50% and 65% respectively. With regard to GWP, it is important to remark the positive effect of the CO_2 sequestered by the biomass which helps to offset the 2% of the green house gas (GHG) emissions into the combustion subsystem. This result derived by spared emissions of heat production by natural gas and of Italian electricity production. While the avoided mineral fertilizer production necessary for fertilization of manure and compost scenarios allows a gain of 4% and 2% GHG emissions all over the life cycle.

EP is an impact category that normally sees its characterization values increase when a biomass source is used (Gasol et al. 2007) due to the diffuse emissions from the application of fertilizers to the crop field. In this case study, for poultry manure and organic fertilizer scenarios, this agricultural activity is responsible two times, for the crops destined to broiler feed and for the end use. For both scenarios, the eutrophication load is almost 50% divided for two subsystems. It is important to remark that the eutrophication impact, for renewable energy scenario, is essentially due to the broiler farm subsystem for 83%.

In terms of AP, emissions from the broiler farm subsystem are the main responsible with a contribution of about 85% for a) and b) scenarios and 97% for the renewable energy scenario. Fertilization subsystem has a load of about 10% for the first two scenarios, and composting adds a 5% more. While, for renewable energy scenario, CP and fertilization subsystems don’t have significant impacts. For renewable energy scenario, despite CP emissions from the boiler have a remarkable contribution of 8.5% in PO, the highest among all impact categories, broiler farm and fertilization subsystems continue to be the main impact factors with 80% and 12% respectively. Also for the other two scenarios, broiler farm and fertilization subsystems are the most important hot spots in photochemical ozone creation potential with about 63% and 36% respectively.

Even to PMF category, emissions from the broiler farm subsystem are the main responsible with a contribution of about 78% for a) and b) scenarios and 96% for the renewable energy scenario.

Fertilization subsystem has a load of about 20% for the first two scenarios, and POF adds a 5% more. While, for renewable energy scenario, CP and fertilization subsystems don’t have significant impacts. Concerning the direct and the undirect energy used throughout the life cycle of poultry manure, the main environmental hot spot remains the broiler farm subsystem both for FD and for CED. The contribution of poultry manure combustion decreases fossil fuels depletion to 10% due to avoided production of heat by natural gas and of electricity. While the avoided mineral fertilizer production allows a gain of 6% of CED with the use of poultry manure and 3% for the organic fertilization.

CHAPTER IV

COMBINING CROP SENSING AND SIMULATION MODELING TO ASSESS WITHIN-FIELD CORN NITROGEN STRESS

4.1 Introduction

It has been demonstrated that site-specific application of N fertilizer provides economic and environmental benefits, such as higher quality and quantity of production (Mulla et al., 1992), higher nitrogen use efficiency (NUE) (Raun et al., 2002), as well as better groundwater quality (Hong et al., 2006). The poultry manure contains a lot of nitrogen (N), so it is essential to evaluate the N in more detail. This management strategy suggests changing within-field N rate and it can be implemented by assessing crop canopy N status with the use of active light sensors. Remote sensing, and lately proximal sensing data, have been used to develop N recommendations, based on algorithms that relate canopy spectral data with yield potential (Raun et al., 2005; Ortiz-Monasterio & Raun, 2007; Solie et al., 2012). The main principle behind these algorithms is the in-season estimation of the N rate necessary to reach yield potential. Martin et al. (2007) identified that the best time for using the sensors for corn management was at the V8 stage (8 leaves stage). Teal et al. (2006) recommended a time window between V7 and V9. The in-season identification of a proper relationship between NDVI and nitrogen plant status can be challenging since NDVI sensors can get saturated due to the rapid biomass accumulation of corn after V6, when LAI > 3 (Viña et al., 2011).

In spite of its positive applications, the use of active light canopy sensors has some drawbacks. Crop sensing provides an estimation of the nitrogen status at a specific time during the growing seasons; however, the sensor-based estimation of the N rate does not account for the stress factors that can impact the crop between sensing and harvest (Heege, 2008). The drawbacks of this approach are that the crop could be either under- or over- fertilized because of the plants response to biotic and abiotic stressors. Furthermore, the development of the algorithms relating NDVI to N rates is based on multiple-years and locations which implies time and resources (Raun, 2004). The limitations described above suggest that a complementary method for in-season assessement of N-status might increase N-rate estimation. Crop simulation models could be used to improve estimation of N-status and optimum N-rate because they simulate crop growth and yield as a response of soil, climate and management information. The Decision Support System for Agrotechnology Transfer (DSSAT) Cropping System Model (Jones et al., 2003) includes different crop growth simulation models, such as the CERES-Maize model (Jones and Kiniri, 1986). This computes daily corn growth and development in response to soil, environmental and management conditions. It has been used extensively to assess maize response to stress conditions (Castrignanò et al., 1994), evaluate management options to mitigate climate risks (Persson et al., 2009) and predict final yield, its variability and the impact of different agronomic practices (Tojo Soler et al., 2007; Hodges et al., 1987). A big limitation when incorporating crop simulation modeling with precision agriculture applications has been running the models across spatial scales. Even though DSSAT is a point-based model, which simulates crop growth on a single point or on a homogeneous unit area, it can be used on precision agriculture studies, which require simulation of the variability of crop behavior spatially across the fields. Several studies have used simulation modeling to support implementation of precision agriculture management strategies. Basso et al (2001) divided a priori the field in homogenous zones in which they run DSSAT; a similar approach was used by Miao et al (2006), who evaluated management zones optimal N rate using CERES-Maize and 15 years of simulations. Paz et al. (1999) applied the same model to determine variable rate N prescriptions in grids across field and to test ability of the model to predict yield variability and crop response to N. To avoid the tediousness of running, calibrating and validating DSSAT separately for each management zone, Thorp et al. (2006) developed APOLLO, a decision support system able to manage input data by zones, and automate the processes of model calibration and validation for each zone. It has been used to study the impact climate on corn yield and nitrogen response (Thorp et al., 2006). This study evaluated the potential for using variable nitrogen management in order to achieve corn production goals and reduce N losses in the system. DeJonge et al. (2006) used the same application for evaluation of the potential of variable rate irrigation. Optimization of the initial values of model parameters to reduce the error between the measured and the simulated data, is another issue in model calibration and it gets more complex when the optimization involves a large date set. The geospatial simulation (GeoSim) plug-in of Quantum GIS is a tool for managing geographic data, conducting spatial model simulation and optimizing model parameters on the spatial scale of the study area (Thorp and Bronson, 2013). GeoSim also allows simulations to be performed over different management units/polygons within a field which facilitate assessment of spatial variability of a specific parameter. The limitation of this type spatial simulation is that each polygon is considered independent from the neighboring polygons. Another function of Geosim is model optimization which is based on a simulated annealing algorithm. As with model simulation, GeoSim does not take into account the spatial autocorrelation between locations when running the spatial model optimization. Thorp and Bronson (2013) tested GeoSim applicability both with Aquacrop (Raes, 2009; Steduto, 2009) and DSSAT models, proving its usefulness for precision agriculture studies. The incorporation of remote sensing data into cropping system models can improve model calibration, especially if spatial simulations are conducted. Remote sensing data have been integrated into crop models to assess and predict crop yield (Seidl et al., 2000), monitor crop growth (Launay and Guerif, 2005), driving crop model simulations (Thorp et al., 2010), reducing within-field data collection and re-calculate missing data (Batchelor et al., 2002), and guide the decision making process for precision agriculture applications (Jones and Barnes, 2000). Different methods have been evaluated to merge remote sensing data into different models. The forcing method is based on the direct replacement of state variables with observed data, losing the information provided by model. This data insertion assumes that the remote sensed data are free of errors, or that the propagation of the observed error into the model is acceptable (Maas, 1987). The optimization method aims to re-initialize or re-parametrize the model by adjusting initial conditions or model parameters to reduce the error between measured (i.e. remotely sensed biophysical data) and predicted data. Some studies have shown that the accuracy of the yield prediction was improved using remote sensed LAI to minimize the error between measured and predicted LAI (Fang et al., 2011). Dente et al. (2008) also mapped with an accuracy of 420 kg ha^{-1} wheat yield after having optimized sowing dates, soil wilting point and field capacity using remotely retrieved LAI. A limitation of this method is the large amount of time required by the optimization procedures. A third method is based on the continuous update of the state variables in the model (Dorigo, 2008) by means of several algorithms such as the Kalman filter (Ma et al., 2013; Ines et al., 2013). Despite the increasing interest of farmers on sensor-optimized N fertilization, its application in real field conditions is still limited because of the lack of a robust methodology able to convert the canopy sensor readings into N rates. The aims of this study were: 1) develop a methodology for combining remote sensor data (NDVI) with CERES-Maize simulations to assess within-field variability of corn N stress and improve estimation of in-season N rates; 2) demonstrate the utility of GeoSim for managing large geospatial dataset, optimizing initial model parameters, and conducting spatial crop simulations.

4.2 Materials and Methods

4.2.1 Study field description

The data used for this study were collected from a precision agriculture project, carried out at Giare di Mira in Italy (45° 20 '52.8" N, 12° 10' 12.0", E) during the 2007- 2009 seasons. This area is classified as nitrate vulnerable zone according to the European Nitrate Directive (91/676/CEE). The climate of the experimental site is sub-humid, with annual rainfall around 96 mm. In an average year, rainfall is highest in autumn (440 mm) and lowest in winter (88 mm). Temperatures increase from January (minimum average: 1.12 °C) to July (maximum average: 29.6 °C). The soil, classified as Aquic Haplusteps, coarse-loamy, mixed, mesic, is alluvial in origin, with a moderate alkaline reaction (Table 4.1).

Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH	EC1:2,5 (mS/m)	SOM g/kg	N_{tot} (%)	C/N	P Olsen (mg/kg)	CEC (cmol/kg)
0-20	64.64	26.96	8.40	7.49	25	8.62	0.06	7.88	13.79	13.78
20-40	62.45	27.87	9.68	7.53	27	8.82	0.06	8.43	13.61	15.48
40-60	66.30	24.46	9.24	7.58	24	6.26	0.05	7.84	12.07	14.48
60-80	66.58	23.97	9.45	7.61	22	6.01	0.04	7.65	8.11	15.36

Table 4.1: Soil average properties

The field experiment compared three crop rotations - continuous corn, corn-wheat, corn-wheat-soybean subject to two management systems or treatments. The first treatment consisted of conventional tillage and high N fertilization rates (High Input – HI) while the second treatment consisted of minimum tillage, cover crops, lower N fertilization rates (Low Input – LI). Experimental fields were rectangular in shape (about 400 m length * 30 m width) with an average size of 1.2 ha. The two longer sides were bordered by 1.4 m depth, 30 m spaced open ditches. Each field was divided into four large plots (0.3 ha size each) where the two management systems with two replications were implemented. Tillage and fertilization practices for both the management systems implemented on corn fields are listed in Tables 4.2 and 4.3.

Year	L.I.		H.I.	
	Date	Tillage	Date	Tillage
2008	28 Apr.	Disk (10 cm deep)	1 Apr.	Moaldboard plow (30 cm deep)
	4 Jun.	Rod weeder (3 cm deep)	1 Apr.	Disk (10 cm deep)
			1 Apr.	Cultivator (10 cm deep)
			4 Jun.	Rod weeder (3 cm deep)
2009	22 Apr.	Disk (10 cm deep)	22 Apr.	Moaldboard plow (30 cm deep)
	18 Jun.	Rod weeder (3 cm deep)	22 Apr.	Disk (10 cm deep)
			22 Apr.	Cultivator (10 cm deep)
			18 Jun.	Rod weeder (3 cm deep)

Table 4.2: Tillage practices implemented in the two treatments.

	L.I.				H.I.			
Year	**Date**	**N kg ha^{-1}**	**P kg haha^{-1}**	**K kg ha^{-1}**	**Date**	**N kg ha^{-1}**	**P kg ha^{-1}**	**K kg ha^{-1}**
2008	1 Apr.	16	20	17	1 Apr.(organic)	50	11	58
	1 Apr.	126			2 Apr.			30
	29 Apr.		5		29 Apr.	36	40	
	15 May	98			4 Jun.	115		
					10 Jun.	115		
	TOT	240	25	17	TOT	316	51	88
2009	22 Apr.	16	20	17	19 Mar.			10
	7 May		5		19 Apr.(organic)	50	11	58
	20 May	98			16 Apr.			25
	3 Jun.	126			7 May	36	40	
					10 Jun.	115		
					18 Jun.	115		
	TOT	240	25	17	TOT	316	51	93

Table 4.3: Fertilizations for the two treatments.

Corn hybrid Pioneer 33T56 was sowed on April 29, 2008 in fields A, B and F, and on May 7, 2009 in fields A, C and E, with a plant density of 8 plants m^{-2}. This early maturity hybrid requires 113 days to reach physiological maturity and 130 growing degree units (GDUs) to reach silking. Corn was harvested with a combine harvester equipped with a yield monitor (GreenStar, John Deer, Moline, Illinois, USA, in 2008; Cebis, Claas, Harsewinkel, Germany, in 2009) on October 1, 2008 (fields A, B and F) and on 03/09/2009 (fields A, C and E). Grain yield data was corrected to dry biomass.

4.2.2 Weather data and soil sampling

Weather data of 2007 - 2009 was provided by a weather station located in Mira, Italy which is 15 km far from the experimental site (45° 26' 7.0794" N, 12° 7' 3.6834" E). At the beginning of the experiment, an apparent soil electrical conductivity (soil EC_a) survey was carried out over the study fields using an EM38DD sensor (Geonics Limited, Ontario, Canada). This sensor collects data in horizontal (up to 75 cm sensing depth) and vertical dipole orientation mode (up to 150 cm sensing depth) which allows collection of soil EC_a at two soil depths. The sensor was linked to a standalone DGPS in order to georeference the sensor readings (1 reading per second). An average of 416 readings per field were collected on a transect of 5.5- 7.5 m in length along each field. Along with the soil EC_a data, soil samples for physico-chemical analyses were collected at several locations within each field. At the center of each plot (4 locations), soil cores extracted to a 80 cm depth were divided into samples every 20 cm depth. In addition, soil analyses were conducted on samples collected in the 0 - 30 cm profile at additional 32 (fields A, B, C) or 36 locations (fields E, F) per field following a regular grid.

4.2.3 Spectral reflectance and Leaf Area Index data collection

Changes in corn biomass and N leaf levels were assessed by collecting spectral data with a handheld active spectrometer, linked to a GPS unit. The APS1-CropCircle (Holland Scientific, Lincoln, NE, USA) measures canopy reflectance at 590 nm (Visible-VIS) and 880 nm (Near Infrared-NIR). An average of 1705 points per field was covered, holding the sensor 0.8 m above the canopy, parallel to the corn rows. The data collected were processed to calculate NDVI (Normalized Difference Vegetation Index), according to the equation provided by Rouse et al. (1974):

$$NDVI = \frac{NIR - VIS}{VIS + NIR} \qquad (1)$$

The data collection was conducted once per season, after side-dress N application, at 73 days after sowing (DAS) in 2008 and 63 DAS in 2009. Indirect Leaf Area Index (LAI) estimations were obtained using a Sunfleck Ceptometer device (Delta-T devices LTD, Cambridge, England). This instrument measures Photosynthetic Active Radiation (PAR) above (incoming radiation) and under the canopy (transmitted radiation), through a probe equipped with 80 light sensors. Twelve observations in a 5 m - radius area from the center of each plot were collected at 73 DAS in 2008. LAI values were derived from PAR values according to the Norman- Jarvis modified model (Norman and Jarvis, 1975).

4.2.4 Data processing

Even though one of the objectives of this study was to simulate the spatial variability of yield and N stress, the data available restricted the scale and the size of the smallest area at which the model was run. Every field was split in polygons of 0.03 ha size eachbecause this is the scale at which soil texture data were available. A shapefile delineating every polygon was created as base layer for the subsequent 32 to 36 site-specific simulations (polygonos for a total of 324 simultaneous simulations per each years), keeping as the center of each polygon the location where soil samples were collected. Average NDVI and yield data were calculated for every polygon. Due to the scarcity of NDVI data in some zones of the fields, polygons with less than 15 measurements point were excluded from the simulation. Although soil texture data at multiple soil depths is required for running the CERES-Maize, the initial soil data from this study was available up to 80 - cm depth only for four locations per field and the other locations had only soil texture estimated at 30 - cm depth. Therefore, for all soil sampling locations, soil texture up to 180-cm depth on 30 - cm depth intervals was estimated by conducting a regression kriging analysis that combined the soil EC_a data (readings at 0 - 75 cm and 0 - 150cm soil depth) and the soil texture data available (Goovaerts, 1997).

An ordinary kriging analysis was conducted to estimate soil EC_a data at the locations with soil texture data. Subsequently, a regression kriging analysis (Goovaerts, 2000) was run to predict the local mean of soil texture as a function of depth, horizontal EC_a, vertical EC_a, and the log of the ratio of vertical EC_a and horizontal EC_a. Eventually, SGems was used to interpolate the regression residuals in 3D and than to regression estimate. Results of spatial interpolations of the upper layer (0 - 20 cm) area.

4.2.5 Model calibration - Cultivar coefficients

The calibration of the cultivar coefficients was conducted using the Generalized Likelihood Uncertainty Estimation (GLUE) method available as a tool in DSSAT. GLUE uses uses a Bayesian Monte Carlo parameter estimation technique that measure the closeness – of - fit of modeled and observed data. GLUE was used to estimate cultivar coefficients related to phenology and growth parameters (He et al., 2010). Cultivar coefficients of a hybrid with the same relative maturity, Pioneer 31G98, were chosen as a basis for this calibration (Tojo-Soler et al., 2007). Because the calibration has to be conducted in absence of crop limiting conditions, the cultivar coefficients were calibrated using 2008 data only from the high yielding polygons (yield > 6500 kg ha^{-1}) of the H.I. treatments (37 polygons). Data from the 2009 season was excluded because of the low amount of precipitation recorded early in the season (May) and during the grain filling period (July). After running 10000 simulations, GLUE estimated the best combination of parameters that minimize the error between the observed and simulated harvested yield and silking and physiological maturity dates (Table 4.4).

P1 (°C day)	**P2 (days)**	**P5 (°C day)**	**G2 (Nr)**	**G3 (mg day^{-1})**	**PHINT (°C day)**
215.5	0.452	884.4	838.6	8.93	48.00

Table 4.4: Cultivar coefficients

P1: thermal time from seedling emergence to the end of the juvenile phase (expressed in degree days above a base temperature of 8 °C) during which the plant is not responsive to changes in photoperiod. P2: extent to which development (expressed as days) is delayed for each hour increase in photoperiod above the longest photoperiod at which development proceeds at a maximum rate (which is considered to be 12.5 hours). P5: thermal time from silking to physiological maturity (expressed in degree days above a base temperature of 8 °C). G2: maximum possible number of kernels per plant. G3: kernel filling rate during the linear grain filling stage and under optimum conditions (mg/day). PHINT: phylochron interval; the interval in thermal time (degree days) between successive leaf tip appearances. (Hoogenboom et al., 2012).

4.2.6 Spatial model calibration using GeoSim

GeoSim allows the optimization of model initial parameters to minimize the error between measured and simulated data through a simulation annealing algorithm. The optimization was conducted for each polygon and consisted of the identification of model parameters that reduced the error between observed and simulated values. Model calibration was a two-step process, the model was frist calibrated for yield and subsequently LAI was calibrated.

1) Model optimization for yield

The model was firstly optimized to reduce the error between the predicted and the observed yield. This calibration involved adjusting soil water balance parameters such as initial soil water content, drained upper limit (DUL) and lower limit (LL). The simulated anneling optimization algorithm within GeoSIM was used for these parameter adjustments. The range of initial values used to run de optimization was 10 to 30 % for initial soil water content, 0.16 to 0.38 for DUL, and 0.03 to 0.15 for LL (Table 4.5). It is affirmed that, this calibration was also intended to capture the spatial variability of measured yeald.

PARAMETER	MAX	MIN
Initial H_2O	0.30%	0.13%
DUL	0.38%	0.16%
LL	0.15%	0.03%
PHINT	60	45

Table 4.5: Maximum and minimum values for optimization.

2) Use of proximal sensing to improve model calibration and simulation

The next step in model calibration involved incorporation of NDVI data to adjust LAI predicted values and therefore improve the estimation of crop N stress spatial distribution. Several studies have shown a relationship between LAI, NDVI and crop N status (Carlston & Ripley, 1997; Ma et al., 1996). For this reason, the model was calibrated to simulate LAI by reducing the deviation between measured and simulated spatial distribution of LAI. Because LAI was not directly measured at the experimental fields, a non-linear relationship was developed first to estimate LAI from NDVI data. LAI values were related to the NDVI average values per experimental unit, using the modified Beer's law (2) (Choudhury et al., 1994):

$$NDVI = NDVI_{max} - (NDVI_{max} - NDVI_{min})\exp(-k'GLAI) \qquad (2)$$

where $NDVI_{max}$ is the index value when LAI is maximum (dense vegetation); $NDVI_{min}$ represents the value for bare soil and *GLAI* stands for green leaf area index.

Because NDVI data were collected before leaves senescence, LAI was considered as GLAI. According to Gitelson et al. (2003), a value of 0.9 was used as $NDVI_{max}$ while $NDVI_{min}$ was set to 0.1 because of the sandy-loam texture of the experimental site. The vegetation extinction coefficient *k* was estimated with a non-linear curve fitting procedure based on the Lavenberg-Marquardt algorithm implemented in Statistica (Statsoft, USA). The comparison between the LAI estimated with equation 2 as a function of NDVI, henceforth called sensed LAI, and the LAI predicted by DSSAT, suggested the need of a second model calibration because at this stage of the calibration the model was not simulating the spatial variability in LAI that was observed from the sensed LAI or NDVI values. Therefore, a sensitivity analysis using data from 2008 and 2009 was conducted to identify the model parameter that improved agreement between sensed and predicted LAI. A preliminary analysis suggested that the phyllochron interval (PHINT) model parameter was the only sensitive parameter able to describe the spatial variability of LAI. Indeed, this parameter controls the interval time between successive leaf tips appearance. By a physiological point of view PHINT depends on the genotype and it is not expected to vary within the fields. PHINT was used as a calibrated lumped parameter -losing in this way its physiological significance- in order to describe processes occurring at the small scale and not properly described by DSSAT. Furthermore, the PHYNT value has some uncertainty even among the same cultivar, because it was not measured, but it was derived from the calibration of the cultivar coefficients. Similarly, spatial optimization of physiological cultivar coefficients was conducted by Thorp et al. (2014) in order to explain cotton yield variability at field level.

4.2.7 Model Validation and statistical methods for performance assessment

The model performance was evaluated by linear regression and Root Mean Square (RMSE), computed as follows:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Yi-\hat{Y}i)^2}{n}} \quad (3)$$

where Yi is the observed value; $\hat{Y}i$ is the predicted value and n is the number of observed values.

The closer the RMSE is to 0, the closer the modeled values are to the measured ones.

4.2.8 Model application - Identification of the optimum N rate

Once the model was calibrated to simulate yield, LAI and subsequently crop N status, simulations were run to determine in-season site specific N rates that will reduce simulated crop N stress. Four different criteria were used to set the optimum N rate: the minimization of N stress, the maximization of crop yield, the maximization of gross revenue, and the minimization of the N surplus. Studies carried out by Ciampitti and Vynn (2011) proved the importance of providing the adequate N supply in the post silking period in order to reach a high yield, especially for recent corn hybrids, which uptake an higher amount of N during the reproductive stage than older ones (Ciampitti and Vynn, 2013). For this reason the identification of the optimal N rates was based on the in-season N rates which minimized the simulated N stress (NSTD) at the beginning of the grain filling (83 DAS in 2008 and 82 DAS in 2009). The model was firstly run to predict N stress (NSTD73 and NSTD65 in the first and in the second crop season, respectively) and its variability on the same day of NDVI measurements. The optimum NSTD83 and NSTD82 were calculated as 50% of NSTD73 and NSTD65, respectively. The maximization of crop yield was identified by running the model in each polygon with increasing N rates from 0 to 150 kg ha^{-1} of N, while the optimum economical N rate was considered as the rate which allowed to level off the price of the N unit and the marginal gross revenue. Eventually, N surplus criterion was based on Veneto Region Action Plan Program of Nitrate Directive. Variable rate N input (N input) was calculated as follows:

$$Ninput = Nup - (No * Ko + Nm * Km)$$

where *Nup* is the N uptake of the corn at the end of the season, *No* is the N rate uniformly applied by organic fertilization and *Ko* is its efficiency, *Nm* is the N rate uniformly applied by chemical fertilization and *Km* is its efficiency. According to Veneto Region Action Plan, N uptake is capped to 210 kg ha $^{-1}$, *Ko* is set 0.4 for solid manure distributed in and *Nm* is 1 for mineral fertilizers.

4.3 Results and Discussion

Regarding model calibration and evaluation – corn yield, initial yield simulations did not represent the variability in soil properties, mainly texture, measured on the fields which could have influenced plant growth and final yield. On average for all the study fields, simulated yield (7828.08 kg ha^{-1}) was close to the measured (7692.62 kg ha^{-1}) one in 2008 while it was strongly underestimated in 2009 (2601.94 kg ha^{-1} simulated Vs 7828.08 kg ha^{-1} observed). Since initial soil water content is considered a factor influencing seed germination, plant health and final yield variability, model calibration of this parameter improved model prediction of within-field yield changes. In order to improve simulated yield values, the DUL and LL soil parameters were considered for model optimization. Following the approach of Ruiz Nogueira et al. (2001) initial soil water content, DUL and LL were adjusted at the same time. After optimization, DUL and LL ranged from 0.16 to 0.37 and from 0.03 to 0.15, respectively. Final yield was predicted with good accuracy, and RMSE values were 298.55 and 269.41 in 2008 and 2009, respectively (Table 4.6).

	Measured	**without calibration**		**Calibration – Initial soil water content**		**Calibration Initial soil water content**	
FIELD	**(kg ha^{-1})**	**(kg ha^{-1})**	**(kg ha^{-1})**	**(kg ha^{-1})**	**RMSE**	**(kg ha^{-1})**	**RMSE**
2008							
A	7345.22	8578.44	1832.12	8183.33	1545.66	7345.86	275.50
B	7368.23	7529.80	1518.09	7401.06	1469.73	7486.63	289.90
F	8376.40	7376.00	2287.59	7339.97	2065.18	8458.19	353.23
2009							
C	8686.86	2538.66	6246.45	2935.25	5959.40	8726.78	251.23
E	6986.68	2665.22	4516.74	2710.59	4683.66	6962.31	288.50

Table 4.6: Impact of model calibration strategies on simulated yield.

Spatial yield variability was thus properly modeled in both cropping seasons and for both treatments, as shown in figure 5, with a standard deviation ranging from 612 kg ha^{-1} (field E, year 2009) to 1895 kg ha^{-1} (field C, year 2009) (Table 4.7).

FIELD	Yield			LAI		
	(kg ha^{-1})	St.dev.	C.V.	Average	St.dev.	C.V.
2008						
A						
HI	6947.06	1718.79	0.25	3.02	0.26	0.09
LI	7744.67	1066.15	0.14	2.94	0.16	0.05
B						
HI	7385.18	1477.79	0.20	2.95	0.18	0.06
LI	7582.44	1518.21	0.20	2.97	0.25	0.08
F						
HI	8555.75	2360.80	0.28	2.99	0.19	0.06
LI	8360.63	1671.12	0.20	3.16	0.24	0.08
2009						
C						
H.I.	9694.11	1472.96	0.15	3.29	0.18	0.06
L.I.	7759.44	1800.54	0.23	2.94	0.25	0.09
E						
H.I.	7062.44	677.85	0.10	2.90	0.06	0.02
L.I.	6862.19	541.97	0.08	2.62	0.11	0.04

Table 4.7: Average and variability of simulated yield and LAI for different fields and treatments

In 2008 the plots receiving the highest N rate were the more productive fields, specially fields A and F, while in field B higher yield was reported in LI plots. In 2009, the HI treated plots had the highest yield values, particularly field C where the interaction between weather, soil type and management could explain the higher crop productivity of ca. 2 t ha^{-1} with respect to LI treatment plots (Table 4.7). In most of the field, the HI treatment exhited the highest CV, therefore more variability._NDVI measurements were collected late in the season (73 and 63 DAS in 2008 and 2009, respectively), which results on NDVI average values of 0.74 and 0.72 for the seasons 2008 and 2009, respectively). A similar pattern was observed in 2009 with high NDVI values (mean 0.73) and low standard deviation (0.03). Regarding the model application - nitrogen stress simulation, in order to evaluate the model as a tool to support in-season variable rate nitrogen application, simulation of the spatial variability of nitrogen stress is necessary. The nitrogen stress model output – NSTD was used to produce nitrogen stress maps on the same dates the NDVI data was collected. In CERES-Maize, NSTD ranges from 0 to 1, with values close to 0 meaning a good N status, while values close to 1 suggest severe nitrogen stress. The nitrogen stress maps at 73 and 68 DAS for the 2008 and 2009 seasons, shows within field changes in the stress level. The low N stress reported in both years, ≤ 0.28 in 2008 and ≤ 0.20 in 2009, is probably due to the high fertilization rates applied and the good weather conditions that probably favored N uptake for the 2008 year. The variability on NSTD, even if low, followed the N fertilization scheme. The LI plots showed higher N stress than HI, especially in 2009, when NSTD was almost 0 in all the polygons of high input treatment (Table 4.8).

FIELD	**Average**	**St. Dev.**	**C.V.**
2008			
A			
HI	0.09	0.06	0.67
LI	0.21	0.04	0.19
Tot	0.15	0.08	0.52
B			
HI	0.11	0.05	0.46
LI	0.15	0.06	0.36
Tot	0.13	0.06	0.43
F			
HI	0.09	0.07	0.80
LI	0.17	0.07	0.41
Tot	0.13	0.08	0.64
2009			
C			
HI	0.00	0.01	2.19
LI	0.14	0.03	0.23
Tot	0.07	0.07	1.02
E			
HI	0.00	0.00	0.00
LI	0.18	0.01	0.04
Tot	0.09	0.09	0.99

Table 4.8: Simulated NSTD variability among the fields.

Due to the lack of any N stress field measurements, the performance of the model on N stress prediction couldn’t be tested. However, the model accuracy on LAI simulation can be considered an indirect proof of CERES-Maize sensibility to represent spatial variability of crop N status. So, in the model application - evaluation of the optimum N rate, the main criteria used to determine the optimum N consisted on the identification of the lowest N rate that minimized N stress. When this criteria was tested, the model suggested N rates much lower that the N rates applied on the experimental plots. The model suggested that the N rates on the HI and LI plots could be reduced by 87.55 kg ha^{-1} and 76.62 kg ha^{-1} in 2008, and 109.56 kg ha^{-1} and 60.57 kg ha^{-1} in 2009, respectively. This strategy aimed to guarantee a good crop nutritional status based on N content in the biomass, but it didn’t take into account the maximum achievable yield as a function of soil fertility. Indeed, the prescription map did not match the variability pattern reported by the soil texture maps. Maximization of crop yield criteria yielded to higher N input in 2008. The average amount was 128.05 kg N ha^{-1} in HI and 79.18 N kg ha^{-1} in LI. High variability of N optimal rate was reported in all the fields, especially in HI plots, which had a standard deviation $\geq$ 45 kg ha^{-1}. Especially in the central area of the experimental site, characterized by an inherit higher soil fertility higher N rates were requested to maximize the production. The average mineral N fertilizations amounted to 83.95 kg N ha^{-1} for HI and 126.96 kg N ha^{-1} for LI treatment. Similar N rates were simulated in 2009 (88.95 kg N ha^{-1} in HI and 112.19 kg N ha^{-1} LI (Table 4.9), with higher N input prescribed for the more fertile polygons.

	N STRESS MINIMIZATION				YIELD MAXIMIZATION				ECONOMIC CONVENIENCE				N SURPLUS MINIMIZATION			
FIELD	AVERAGE	MAX	MIN	ST.DEV.	AVERAGE	MAX	MIN	ST.DEV.	AVERAGE	MAX	MIN	ST.DEV.	AVERAGE	MAX	MIN	ST.DEV.
2008																
A																
HI	23.89	50	0	15.77	58.89	150	0	50.05	44.44	150	0	52.61	0	0	0	0
LI	11.11	20	0	4.71	121.11	150	90	14.91	100.56	120	40	18.62	21.67	70	0	19.17
Tot	17.5	50	0	13.17	90	150	0	48.17	72.5	150	0	48.19	10.83	70	0	17.3
B																
HI	28.46	60	0	15.73	91.54	150	0	49.13	50	120	0	43.01	0	0	0	0
LI	26.36	30	20	5.05	127.27	150	100	22.84	97.27	150	30	35.8	0	0	0	0
Tot	27.5	60	0	11.89	107.92	150	0	42.63	71.67	150	0	45.84	0	0	0	0
F																
HI	30	90	0	25.12	101.43	150	0	55.59	57.14	100	0	42.5	0	0	0	0
LI	26.67	50	0	11.55	132.5	150	100	16.03	123.33	150	90	21.88	4.17	20	0	7.93
Tot	28.46	90	0	19.74	115.77	150	0	44.38	87.69	150	0	47.78	1.92	20	0	5.67
2009																
C																
HI	5.56	20	0	7.05	93.89	140	0	38.37	38.33	80	0	27.92	7.22	30	0	9.58
LI	21.11	40	0	13.23	110	150	0	44.46	77.78	150	0	54.72	57.78	90	0	26.47
Tot	13.33	40	0	13.09	101.94	150	0	41.74	58.06	150	0	47.26	32.5	90	0	32.28
E																
HI	5.33	20	0	7.43	84	150	0	68.22	26.67	150	0	43.53	1.33	10	0	3.52
LI	53.75	80	50	8.85	114.38	150	0	49.12	86.25	150	0	48.29	0	0	0	0
Tot	30.32	80	0	25.88	99.68	150	0	60.14	57.42	150	0	54.47	0.65	10	0	2.5

Table 4.9: N rate fort the different fertilization strategies.

Considering the previous undifferentiated fertilization, in 2008 the total mineral N amounted to 234.95 kg N ha^{-1} in HI and 240.96 kg N ha^{-1} in LI plots, while in the following crop season HI treatment reported 239.95 kg N ha^{-1} and LI 226.19 kg N ha^{-1}. This total rate did not substantially differ from the mineral N effectively provided in the experiment (266 kg N ha^{-1} in HI and 240 kg N ha^{-1} in LI). Apply such amount of N could be expensive for the farmer, indeed N fertilizations cost is one of the heaviest expenses of corn production, furthermore, high rates are not always related to adequate yield increases. On the other hand, high N rates could result in water nitrate pollution which can be a relevant issue in the Venice Lagoon watershed. As suggested by Paz et al. (1999), a third strategy was applied to assess the optimum N rate able to optimize the net revenue. N optimum rate based on economic criteria resulted in lower N optimum rate that those aimed to maximize of crop yield. The average rate was reduced by 26% in 2008 and 43% in 2009 (Table 4.9). As in the prescription maps aiming to optimize final production, optimum N rate is driven by soil fertility and previous uniform fertilization management in both the years. Polygons located in areas characterized by lower sand and higher soil organic matter reported higher N rates while on average LI plots requested to be fertilized almost the double than HI. Eventually, the last approach aiming to minimize the N surplus according to the European Nitrate Directive resulted in very low or even null N rates for the majority of the polygons. In 2008, only LI plots required to be fertilized, although the average simulated rate is lower than 10 kg N ha^{-1}. In 2009 field E required almost a null fertilization (only two polygons reported an optimum rate of 10 kg N ha^{-1}), while field C required on average of 57.78 kg N ha^{-1} for LI treatment and 7.22 kg N ha^{-1} for LI. Furthermore, in some of the low fertility polygons even the 0 N input scenario resulted in N surplus > 0, demonstrating that in those areas even the previous uniform applied fertilizations caused over-fertilization. This criteria could be particularly useful for fields located in nitrate vulnerable zones, where farmers are allowed to fertilized with an average N amount established by the Action Plans of the European Nitrate Directive. With this approach, this average amount could be specifically managed for different zones across the field. Finally, when adopt model simulation for precision agriculture and site-specific application, it’s essential to simulate crop growth and yield spatially. GeoSim was able to automate spatial simulations and facilitated the optimization of a point-based model for predicting yield and nitrogen stress across the fields, which makes it a very promising tool for precision agriculture applications. Furthermore, the application of a model for precision agriculture purposes, is limited by the complexity of the input data, which are not often completely available. This appears to be particularly meaningful when running models as DSSAT, requiring a large input dataset. A lack or uncertainty on model input data could be partially overcome by the optimization of initial parameters. GeoSim operated an optimization of soil initial water content and hydraulic parameters, providing accurate yield estimation, which was not negatively influenced by model optimization for LAI. The incorporation of proximal sensed-derived data into the model guaranteed the accuracy of nitrogen stress simulation, due to the relationship between NDVI, LAI and N stress. Simulating N stress could be useful in order to manage an in-season site-specific fertilization, increasing N efficiency but it could not guarantee to satisfy other criteria such as the maximum achievable yield, the economic convenience or the environmental impact of the fertilization.

CHAPTER V

SUMMARY AND CONCLUSIONS

The research was developed according to three lines:

a) use of microorganisms during broiler standard indoor system farm to reduce environmental impacts, especially with regard to ammonia (NH_3). These treatments have been carried out on the drinking water (DW) and on poultry manure (PM);

b) different treatments and uses of poultry manure, in order to complete the cycle of this co-product of the production of the poultry meat. These treatments concern the usual direct spread of poultry manure in the field (DFS), the production of organic fertilizer (POF) and direct combustion (CP);

c) models to identify the optimum nitrogen (N) to be administered to crops. This last line of research is not strictly connected to the first two lines of research, but it allows us to better understand how to evaluate the use of N which is very present in poultry manure.

Regarding the first line of research, this has been developed in broiler farms in North - East Italy. The use of microorganisms to control emissions is essential especially for NH_3. High concentrations of NH_3 result in poor performance in broilers (Deaton et al., 1984; Wang et al., 2011: Ahmed et al., 2014) and research suggested that 25 ppm NH_3 should not be exceeded in poultry houses (Carlile, 1984; Moore et al., 1996). Finally, reduce NH_3 volatilization retain N in poultry manure for fertilizer value, and as a result negate the detrimental environmental impacts of NH_3 loss to the air. A range of chemical and biological additives are known to reduce NH_3 volatilization from poultry manure (Van Der Stelt, 2007). Furthmore, marketing statements generally claim that volatilization of NH3 is reduced by stimulating immobilization Of NH_4 by microorganisms, thus reducing its concentration in livestock (Mccrory et al., 2001). The product used is generally called LW (for the confidentiality of the manufacturer). It was applied to the poultry manure either directly or through the drinking water and comparing the results with non-LW controls (CL). The timing of the application PM was at the beginning of the production phase, half of the production cycle and finisher for each shed treated. Regarding the DW, the applications took place once a week. The LW consist of Bacillus Licheniformis, Bacillus Cereus and yeasts that are extract of fermentation from thermally dried microorganisms, other types of organisms, dextrose, sodium chloride and sodium bicarbonate. We want to clarify that this research concerned the application of this product (LW) and its effect on emissions and therefore on possible environmental impacts. On the other hand, it did not concern a microbiological analysis. The LW reduce poultry manure NH_3 and/or NH_4^+ levels as bacteria oxidize them to nitrite and nitrate, NO_2^- and NO_3^-, respectively (Jacobson et al., 2001; Kim et al., 2004; Patterson, 2005). It contains denitrification bacteria that convert nitrates into gaseous nitrogen (N_2) also and/or stimulating immobilization of NH_4^+ like demonstrated by (Mccrory et al., 2001). To assess the environmental impacts of broiler farms and how the LW product can positively influence impacts, the Life Cycle Assessment (LCA) methodology was used. The goal of the work was to apply the LCA method from ''cradle to farm gate'' to assess the environmental impacts of microorganisms LW in order to reduce the emissions of NH_3 in particular, but N_2O and CH_4 also, and therefore, to identify possible opportunities for reducing environmental impacts within the management systems. The functional unit was 1 kilogram of broiler live weight (FU) similar to other authors (Williams et al., 2006; Leinonen etal., 2012; Wiedemann et al., 2012). The environmental impact categories considered were: Climate Change (CC) expressed as kg CO_2 eq., Particular Matter Formation (PMF) expressed as PM10 eq., Terrestrial Acidification (TA) expressed as kg SO_2 eq., Eutrophication (EP) expressed as kg PO_4^-, Photochemical Oxidation expressed as C_2H_4 eq. and Cumulative Energy Demand (CED). The results showed that the average amount of NH_3 produced in the CL sheds was higher of about than those treated (PM, DW). In particular, 0.008 kg of NH_3 was produced on the DW sheds, while on the LM sheds an average of 0.005 kg of NH_3 was produced. These values are always in comparison with CL and always refer per 1 kilogram of broiler live weight (FU). The main environmental burdens from each whole treatments (PM, DW, CL) per 1 kilogram of broiler live weight (FU) are the following. The results show that the PM and DW treatments had lower TA compared with that of CL, and the differences between DW and PM were statistically significant ($P<0.05$). The same considerations can be made for PMF and EP. Feed caused higher overall environmental impacts than any other materials involved in production; for example 81% in CL and 79% for PM and DW, respectively. Housing emission (in particular NH_3) had the second highest impact (5-22%) followed by electricity (mainly ventilation, feeding, and lighting). In particular, for TA, the PM can have an environmental impact of about 11% less than CL and an avoided impact of about 5% for DW. Furthmore, significant were the environmental impact avoided of PM and DW compare to CL regarding PO. Precisely, the avoided impact is about 9% for PM and about 3% for DW. Finally, compared with EP. About broilers, there are some different studies to compare to this one, they all analyzed the LCA of broilers production, but they had different aims. In United Kingdom, there was a study about the comparison of three different types of raising and the impacts connected, in order to identify how to reduce them (Leinonen I., et al., 2012). The performances and the results came from different systems and types of management, so the results of these studies showed only that a similarity between different reality could exist and they couldn’t be considered as an average of all production systems. Another interesting study was about the comparison of broiler production to that of pork and beef (Gonzalez-Garcia S., et al., 2013), made in Portugal. As in our study, the feed production results in the main responsibility of environmental damages, while heat production was the factor that less contributed to the impact. Finally, in the category of CC it showed less emissions in 77% of the Monte Carlo model simulations, compared to the management CL, and in 69%of the simulations compared to the PM. In TA, DW was better in 81% of the simulations than CL and in 74% of the simulations when compared to the PM. In conclusion, concerning the environmental impact, it can be suggested that in the intensive system of broiler production, a management where there is a treatment with these kind of microorganisms made through the PM and DW would be beneficial, but more researches are needed, in order to understand the effect of this treatment outside the breeding (use of the exhausted poultry manure).

Instead, regarding the second line of research, this includes three types of poultry manure use. One use considers the direct spread (DFS) of the poultry manure which is the most used method in Italy. Then it was considered the production of organic fertilizer (POF) in order to enhance the poultry manure and then allow to transport the product very far from the production areas. Finally direct combustion (CP). This choice was made as it reflects more the choice of combustion made in Italy, but allowed to compare the data with England also. The search for solutions to manage the poultry manure is also born from the place where it is produced. The area is the same as the first line of research, North - East Italy. The broiler farms in this area are a lot and all are characterized by the absence of field where the poultry manure could be spread. The poultry manure co-product, has excellent amounts of nitrogen and phosphorus (Chamblee and Todd, 2002), but also a good heating value of about 7 MJ kg^{-1}. A proper management of the poultry manure is highly recommended by the European Union with the Nitrate Directive (European Union 1991), that limits the spreading rate of animal manure and with the electricity production from renewable sources directive (European Union 2001), that fosters an internal supply of energy market and a saving emissions of greenhouse gases (Taylor 2008; Kim and Dale 2004). The aim of the current research line was to evaluate the environmental impacts of broiler production associated to two different treatments of poultry manure and its end use as agronomic fertilizer. The Life Cycle Assessment (LCA) methodology was also used to assess the environmental impacts of this second line of research. The functional unit considered is 1000 kg of broiler manure ready to be treated was the functional unit (FU). The LCA system model used in the analyses was developed originally at Cranfield University (Williams et al. 2006, 2016) and subsequently developed further in a partnership with University of Padova (Guercini and Sgorlon, 2016, unpublished data) and Scotland's Rural College, Edinburgh (Leinonen et al. 2012, 2016). Regarding the POF the plant is in North-East area of Italy, usually total period is of 90 days of which 30 days of the high rate temperature stage and 60 days of curing phase. This process involves some disadvantages such as loss of ammonia (NH_3) and other nutrients due to a low C/N ratio (Gray et al., 1971), the use of capital goods, infrastructure, worker cost and agriculture land occupation (Sweeten, 1988). The building structure consists of a concrete barn with airtight systems to allow the air aspiration and the exhaust air treatment by a biofilter. Instead, regarding the CP, the CP of poultry manure provides combined generation of heat and electrical power. The subsystem has an efficient combustion, gas stay more than 2 seconds at 850 - 950 °C of temperature in a highly oxidative combustor. Then, gas yield their enthalpy to the diathermic oil recovery system raising its temperature up 300 °C. The warm diathermic oil arrives to the Organic Rankine Cycle system to produce electric energy. Flue gas are treated by a catalyst in which NH_3 is sprayed and nitrogen oxides (NO_2) are reduced into N_2, and by a cyclone and a bag house filter that removes dust to less than 10 mg/Nm^{-3}. Poultry manure caloric value, that is the quantity of energy released by each unit of combustible mass, increases linearly with decreasing moisture content, that in the operative line must be lower than 45%. Finally, regarding the DFS, manure, organic fertiliser and ash, as has been said, have a nutritional capacity of N, P_2O_5 and K_2O and an amendment function to the high C content in poultry manure and organic fertiliser. The amounts of potentially absorbable nutrients by crops are counted to one of the three fertilizers (poultry manure, organic fertiliser and ash) which compensates the production of the spared mineral fertilizer for each type of fertilization (Leinonen et al., 2012). To assess the emissions of three types of fertilizations DeNitrification-DeComposition (DNDC, 2000) model was used. The environmental impact categories considered are: Global Warming Potential (GWP_{100}) expressed as kg CO_2 eq., Acidification (AP) expressed as kg SO_2 eq., Eutrophication (EP) expressed as kg PO_4^- eq., Photochemical Oxidation (PO) expressed as kg C_2H_4 eq., Particular Matter Formation (POF) expressed as PM10 eq., Fossil Fuel Depletion (FD) expressed as MJ and Cumulative Energy

Demand (CED) expressed as MJ. The results between DFS to CP comparison, a reduction in the environmental loads was possible in almost all impact categories selected. An important improvement has been achieved in PO and EP when poultry manure is combusted with a decrease of 27.7% and 33.3% respectively. Other impact categories to point out are: AP, FD and PMF, with a diminution of about 10% for the first two categories and 18% for the last one. These results come from strong reduction of NH_3, CH_4 and VOCs emissions during outdoor storage and field spreading (Bengtsson and Seddon, 2013; Katajajuuri, 2007; Williams et al., 2006). With regard to GWP, it is important to remark the positive effect of the CO_2 sequestered by the biomass which helps to offset the 2% of the green house gas (GHG) emissions into the CP. Instead, when poultry manure scenario is substituted by organic fertiliser (POF) manufacturing seems to present an increasing in the environmental burdens in almost all impact categories. However, it must be considered that this solution has a greater environmental impact, but it allows the product to be transported far from the production area. Increments in environmental loads at any impact category are mainly due to emissions derived from the POF utilization, mostly in EP category +16%, as well as FD +5% and CED +8% due to the high energy request. A small worsening has been registered in PMF +1% and AP and GWP with about +3%. For DFS and POF both, the EP load is almost 50% divided for two subsystems. Concerning the direct and the undirect energy used throughout the life cycle of poultry manure, the main environmental hot spot remains the broiler farm subsystem, where the poultry manure is produced, both for FD and for CED. The contribution of poultry manure combustion decreases fossil fuels depletion to 10% due to avoided production of heat by natural gas and of electricity in CP scenario. While the avoided mineral fertilizer production allows a gain of 6% of CED with the use of poultry manure and 3% for the organic fertilization in POF scenario. It remains to be evaluated economically if the major environmental impacts of POF can be justified by solving the problem by bringing the poultry manure away from the place of production. Instead for CP, it remains to be assessed whether the good environmental performance remains the same even with other combustion systems. Instead, it can be said that the DFS, leads to less environmental impacts of POF and more environmental impacts of CP. However, it must be remembered that in areas with high density of livestock and therefore manure production, this process enables a product with added value and can therefore be transported at long distances away from the production area.

Finally, the third research line, despite of its positive applications, the use of active light crop canopy remote sensors for in-season site-specific nitrogen (N) management has some drawbacks. This last line of research is not strictly related to the other two lines of research, but it is important to evaluate the correct use of nitrogen (N) in the field. This is because even the poultry manure has a high N content. Furthermore, used canopy sensing-based N rate algorithms use in-season estimation of canopy N status to prescribe N rate need to reach yield potential but is does not account for crop streses between sensing and harvest. Two scenarios were considered, one with high input of N (Hi) and one with low input of N (Li). So, has been possible develop and test methodology for combining normalized difference vegetation index data (NDVI) and simulating the assess spatial variability of corn N stress and in-season N rate. The model was first optimized to properly predict the yield, and subsequently to match the simulated and the NDVI-derived leaf area index (LAI). Model accuracy in yield estimation was reached by soil parameters optimization and was not negatively influenced by model optimization for LAI. The model suggested that the N rates on the HI and LI plots could be reduced by 87.55 kg ha^{-1} and 76.62 kg ha^{-1} in 2008, and 109.56 kg ha^{-1} and 60.57 kg ha^{-1} in 2009, respectively. This strategy aimed to guarantee a good crop nutritional status based on N content in the biomass, but it didn’t take into account the maximum achievable yield as a function of soil fertility. Manage an in-season site-specific fertilization aiming to minimize N stress could N efficiency not guarantee to satisfy other criteria such as the maximum achievable yield, the economic convenience or the environmental impact of the fertilization. So it is still to be evaluated how Hi has more or less impact on the environment than Li, perhaps integrating the study with an LCA analysis.

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