Theses of Doctoral (PhD) Dissertation

ASSESSMENT OF ENVIRONMENTAL BURDEN ASSOCIATED WITH BROILER CHICKEN PRODUCTION BASED ON A CIRCULAR APPROACH

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1. BACKGROUND AND OBJECTIVES OF THE DOCTORAL DISSERTATION

The number of chickens bred around the world has doubled since the 1990s (FAOSTAT, 2020). This intensive growth is mainly due to population growth, as chicken meat is a very important and rapidly producible source of protein (CHIA et al., 2019; NALUNGA et al., 2021). Because of a rapidly growing population, which is expected to exceed 9 billion by 2050, the livestock sector is currently confronting one of its greatest difficulties. Given land and water use limits and regulations that limit producers, increasing production capacity is difficult. Sustainability is therefore a key issue in the livestock sector (PELLETIER and TYEDEMERS, 2010).

In general, animal production systems have a large environmental impact, and their polluting effects require increased environmental protection (STARME, 2011). The sector also has an impact on climate change, nitrogen and phosphorus cycling, and biodiversity loss due to changes in land use patterns (TILMAN et al., 2001; MARGULIS, 2003; SOLOMON et al., 2007; ARIMA et al., 2011; CARPENTER és BENNETT, 2011; BELLARBY et al., 2012). To protect and preserve the environment and natural resources, the Common Agricultural Policy (CAP) introduced greening in 2015, which refers to agricultural practices that are environmentally beneficial and less damaging to the environment (NAK, 2017; 2018). The European Union also introduced the European Green Deal (EU Green Deal) to comprehensively address environmental problems, with the main goal of making Europe climate neutral and sustainable by 2050 (INTERNET1). Among the objectives of the green deal for agriculture, those aimed at reducing the use of fertilizers and favouring the use of organic fertilizers are very important. Because although fertilizers provide nutrients to vegetation quickly, in large quantities and in easily accessible forms (SCHOLL and NIEUWENHUIS, 2004; CHEN et al., 2007; HAN et al., 2016), their use can have several negative effects from an environmental point of view. Livestock products like manure and other organic materials, which aren't beneficial for livestock production, can help replenish soil resources and even serve as a fertilizer substitute (MÉZES et al., 2015; HE et al., 2016, 2020; GORLICZAY et al., 2021). Organic fertilizers were used to replace nutrients taken up by plants in Hungary until the first third of the 1900s, but intensive farming - with the development of chemical fertilizers with higher active ingredient content - has driven their use to the background. It is important, however, that organic fertilizers are properly treated and disposed of before application, as untreated fertilizers can be dangerous. With rapidly rising livestock industries such as broiler production (CHIA et al., 2019; NALUNGA et al., 2021) - which is expected to become even more important in the future from a food perspective (KASULE et al., 2014; ENAHORO et al., 2018; VAN HARN et al., 2019; JANKOVIĆ et al., 2020) - the issue of recycling increasing amounts of manure has grown increasingly critical in recent years. One alternative approach of manure management is composting, which is a well-known and used method for the disposal of organic wastes and by-products (FILEP, 1999; MODDERMAN, 2020). The material recovery (composting) of broiler manure was the subject of my thesis. The method used to determine the key environmental burdens and critical points in the process is known as life cycle assessment. Not only manure processing but also animal and crop production operations have been included in order to acquire a more complete picture of the potential environmental concerns. These three sectors are closely interlinked, forming a circular economy, thus eliminating the linear structure. As a research method, ISO14044:2006, "Environmental management. Life cycle assessment" was used. Before applying these manure products, it's essential to understand the characteristics and plant effects of these, therefore I set up a pot experiment with the application of composted and pelletized broiler litter (CPPL) and a maize (Zea mays L.).

In summary, my objectives were:

1. Investigate and assess the environmental impacts of a circular economy (broiler chicken farm and related production sectors) using a life cycle assessment method, applying the CML IA baseline impact assessment method, based on eleven impact categories. Within this, the following objectives were set:
    1.1 Identify the environmental critical points of broiler chicken farming based on input and output material and energy flows per 1 t live weight broiler chicken, separately examining the rotations of summer and winter months. The objective is motivated by the limited availability of national and international experience on the environmental impact of broiler chicken production. Life cycle assessment of the Hosoya composting plant, identifying critical points in the production technology.
    1.2 Evaluate the role of CPPL as a potential alternative to chemical fertilizers by exploring, evaluating and comparing the environmental impacts of producing CPPL at the Hosoya composting plant and the production of different fertilizers, as such an evaluation has not been done before. My objectives were therefore to:
        1.2.1 Determination the environmental impact of the production of 1 kg CPPL compared to the environmental impact of the production of different chemical fertilizers (ammonium nitrate (AN), calcium ammonium nitrate (CAN), urea, triple superphosphate (TSP), monoammonium phosphate (MAP), potassium chloride (KCl);

        - 1.2.2 Determination of the environmental burden of production per 1 kg of active substance (separately for 1 kg of N, 1 kg of P2O5 and 1 kg of K2O);
        - 1.2.3 Determination of the environmental burden of production for complex nutrient replenishment of a field of 100 ha (with CPPL and combinations of N, P and K fertilizers);
        - 1.2.4 Evaluation of the cost of 1 kg of N, P2O5 and K2O for CPPL and fertilizer combinations.
    - 1.3 Evaluate the critical points of the cultivation technology for the two most important crops, for 1 t of harvested maize (Zea mays L.) and winter wheat (Triticum aestivum L.), when nutrient replenishment with CPPL and when with different combinations of N, P and K fertilizers.

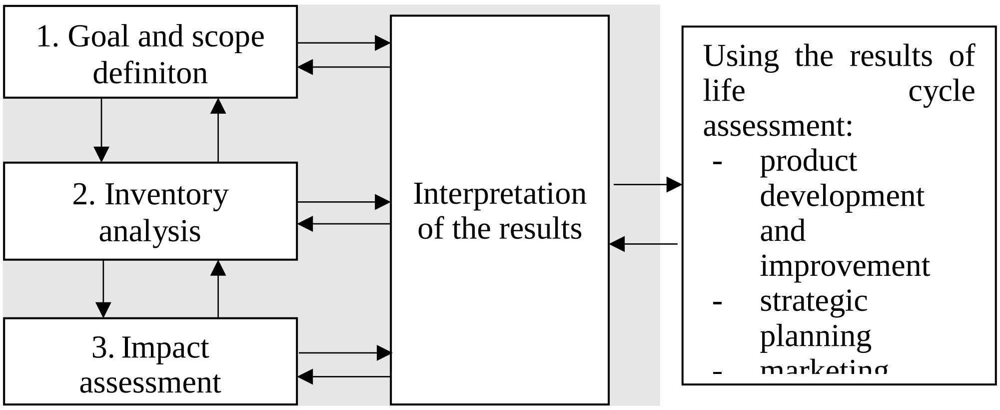
2. In addition to the environmental impact, my objective was to study and evaluate the effect of CPPL on maize (*Zea mays* L.), winter wheat (*Triticum aestivum* L.) and sunflower (*Helianthus annuus*) test crops compared to the effect of ammonium nitrate (hereafter: AN) fertilizer under pot experiment conditions.

2. MATERIAL AND METHOD

2.1. Life cycle assessment of the circular economy

The steps of the life cycle assessment are summarised in Figure 1.

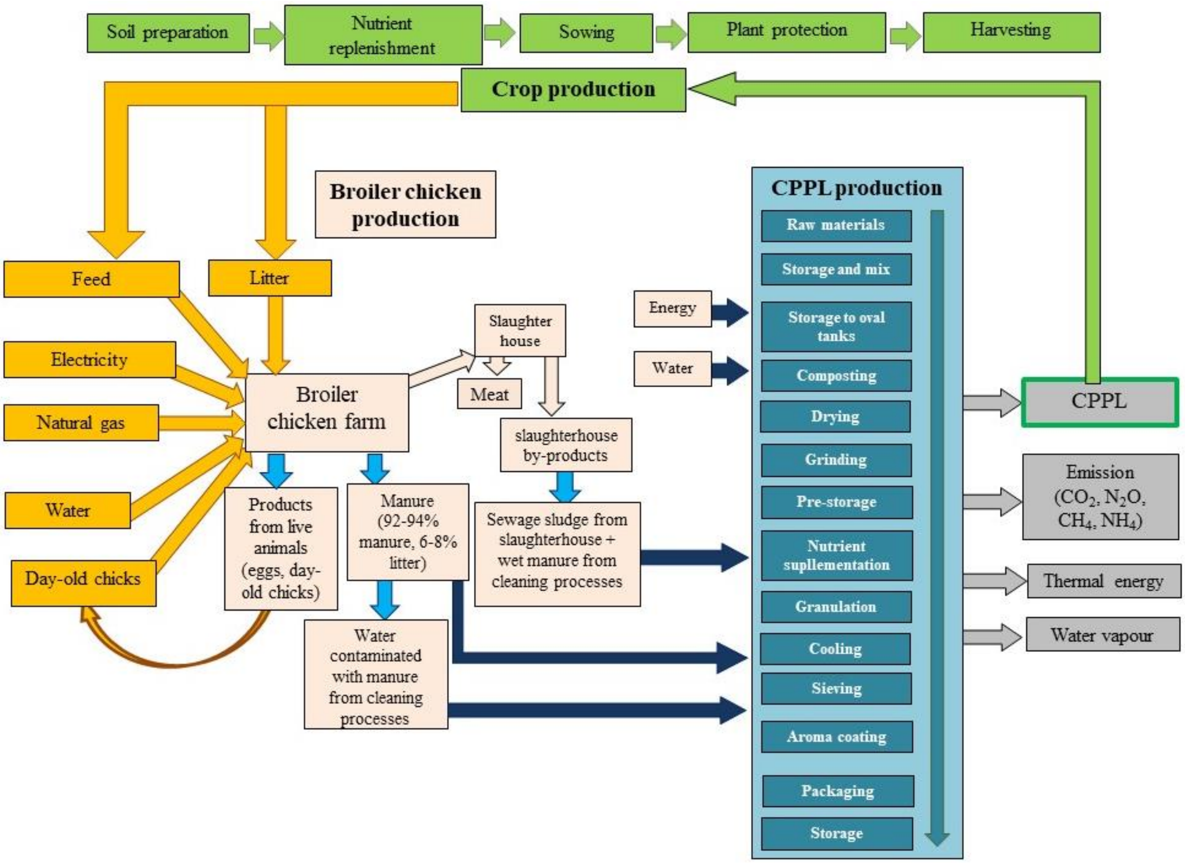
Figure 1: **Steps of life cycle assessment**



References: JENSEN et al., 1997.; ISO 14040:2006. (Own editing, 2019)

The three sectors underpinning the research (1. intensive broiler production, 2. poultry manure composting followed by pellet production (Hosoya composting plant), 3. crop production (maize (*Zea mays* L.) and winter wheat (*Triticum aestivum* L.)) and the interrelationship between the three sectors are summarised in Figure 2.

Figure 2: **Systems of a circular economy**



2.1.1. Defining the goal and system boundaries of life cycle assessment (Step 1)

The main focus of the analysis is a life cycle assessment of the material and energy flows during the production and use of broiler manure pellets. In setting the system boundaries, however, research cannot be limited to the composting and granulation process. In order to get a more accurate picture of the environmental impacts of CPPL production, broiler chicken production, maize and wheat production cannot be ignored.

Aim of the life cycle assessment of broiler chicken production: my aim was to determine the environmental critical points of production per 1 tonne live weight of broiler chicken during summer and winter rotations.

Aim of the Hosoya composting plant life cycle assessment: the main objective of the analysis is to assess the role of CPPL as a potential alternative to fertilizers by identifying, evaluating and comparing the environmental impacts during the production of CPPL at the Hosoya composting plant and during the production of different fertilizers. Environmental impacts were determined for the following quantities:

- *For the production of 1 kg of final product:* Assessment of environmental impacts during production of 1 kg CPPL compared to the environmental impact of producing 1 kg chemical fertilizer (AN, CAN, urea, TSP, MAP, KCl).
- *For 1 kg of active substances:* environmental impacts were identified and assessed separately for 1 kg of N, 1 kg of P_2O_5 and 1 kg of K_2O for both CPPL and chemical fertilizers.
- *For the nutrient supply of a 100 hectares field*: The nutrient (NPK) supply of a 100 hectares field with 1.5 t/ha of CPPL (based on the suggestion of Baromfi-Coop Ltd. and SZABÓ et al.'s [54] method), and with chemical fertilizer combinations with an equivalent NPK supply to analyse the environmental impacts of CPPL as a multi-element fertilizer.

Aim of the life cycle assessment of maize and winter wheat crops: My goal was to compare the environmental impacts of growing forage maize and wheat per 1 tonne of harvested crop and to identify the critical points of the cultivation technology when nutrient replenishment is done with CPPL and when different combinations of chemical fertilizers are used (which combinations are detailed below).

2.1.2. Life Cycle Inventory Analysis (Step 2)

The Life Cycle Inventory (LCI) quantifies the input and output data for a product system and includes the necessary data collection and calculation procedures. These input-output data may relate to resource use, soil, water and air emissions associated with the system. The interpretation after the LCA study is carried out can be derived from these data, which also serve as the basis for the life cycle impact assessment.

Inventory analysis of broiler chicken production: in the life cycle assessment of broiler chicken production, I collected separately the inputs and outputs needed for production during the rotations of the summer (April to September) and winter months (October to March). The input and output data for the analysis were provided by Baromfi-Coop Kft. and the publicly available Integrated Environmental Authorisation for the respective farm. Data that were not available were provided by literature data and values found for material and energy flows in the life cycle assessment software. The data extracted from the openLCA software were converted to 1 tonne live weight for easier comparison with literature data.

Inventory analysis of the Hosoya composting plant: Part of the input datas for the life cycle inventory analysis (manure and sludge, water, fuel) was provided by the composting plant, and part by my own calculations (electricity), literature data and data from the openLCA database. Based on the plant data, I first calculated the data for one loading of a Hosoya tub. Finally, using the existing data, I recalculated the material and energy flows required to produce 1 kg of CPPL, for easier comparison later, and then entered these data into the openLCA software. The material and energy flows needed to assess the environmental impact of fertilizers were provided by the Agribalyse database. The assessment of the environmental impact of chemical fertilizers was based on the production process in the factory itself, i.e. raw materials (e.g. ammonia for AN, CAN, urea and MAP fertilizers; dolomite and nitric acid for CAN fertilizer; phosphate rock for TSP and MAP; phosphoric acid for TSP; potash for KCl fertilizer), electricity, heating, water, packaging, etc.

Inventory analysis of maize and winter wheat cultivation: for the LCA of crop production processes, the analysis have been based on the two most important field crops grown in Hungary, maize and winter wheat. Environmental impacts were quantified per 1 tonne of harvested crop.

2.1.3 Life cycle impact assessment (Step 3)

In practice, software is used to carry out life cycle assessments. For the analyses I have chosen the OpenLCA software (INTERNET2). In this study, I used the CML IA baseline impact assessment method. The method assesses the processes and products under study according to the 11 most commonly used impact categories of life cycle interpretation (Table 1) (GUINÉE et al., 2002; GEIER et al., 2015).

Table 1.

The applied impact categories

Name of impact category	Abbreviation	Unit of measure
Abiotic depletion potential for elements	ADPe	kg Sb-equivalents
Abiotic depletion potential of fossil fuels	ADPf	MJ
Acidification potential	AP	kg SO_2-equivalents
Eutrophication potential	EP	kg PO_4-equivalents
Global warming potential	GWP	kg CO_2-equivalents
Ozone layer depletion potential	ODP	kg CFC-equivalents
Photochemical oxidation potential	POP	kg C_2H_4-equivalents
Human toxicity potential	HTP	kg 1.4-DB-equivalents
Fresh water aquatic ecotoxicity potential	FAETP	kg 1.4-DB-equivalents
Marine aquatic ecotoxicity potential	MAETP	kg 1.4-DB-equivalents
Terrestrial ecotoxicity potential	TETP	kg 1.4-DB-equivalents

The analyses were carried out in the free downloadable Agribalyse database, which contains a large amount of data for all the necessary analyses (COLOMB et al., 2015; KOCH and SALOU, 2020; ASSELIN-BALENÇON et al., 2020).

The results of the life cycle assessment (Step 4) are detailed in the Results and their evaluation section.

2.2. Comparison of the effects of CPPL and AN in pot experiment

A comparative analysis of the effects of CPPL and AN fertilizer on test crops was carried out under laboratory conditions. During my research, several crops - field and horticultural - were grown in pot experiment on quicksand soil, but in this thesis, the results obtained with maize, winter wheat and sunflower will be presented.

The pot experiments were set up in the laboratory of the Institute of Water and Environmental Management, University of Debrecen.

My objective was to evaluate the effect of CPPL on maize compared to the effect of the AN fertilizer treatments. As a result of the comparison, I wanted to answer the question: can concentrate chemical fertilizer be replaced by CPPL?

The experiment lasted 21 days. After the experiment's elimination, the root and stem length (seedling length) of the germinated plants were measured, and the dry matter content, germination %, Vigour index were calculated. Chlorophyll and carotenoid content were determined by destructive method. The absorbance of the plant samples were measured using Secoman Anthelie Light II UV-VIS spectrophotometer.

The results measured in the laboratory experiments were entered into Microsoft Office Excel and then created databases from the raw data. Statistical analysis of the data was performed using R software in the R Studio user environment. The normal distribution of the data was tested using Shapiro-Wilk test at 5 % significance level (p=0.05). Where data were found to be normally distributed, Duncan's test was used to quantify statistical differences. When normality was not met for the groups, the Kruskal-Wallis test was used. The aim of the pot experiment was to demonstrate a statistically verified difference between CPPL and AN.

3. RESULTS

3.1. RESULTS OF THE LIFE CYCLE ASSESSMENT

3.1.1. Environmental impacts of intensive broiler chicken production

The environmental impact of 1 tonne live weight of broiler chickens is presented in Table 2, with separate values for summer and winter rotations for each impact category.

Table 2.

Results of the life cycle assessment of the broiler chicken production

Impact categories	Summer rotations	Winter rotations
ADPe (kg Sb-equivalent)	0.0045	0.0046
ADPf (MJ)	13 186	16 536
AP (kg SO_2-equivalent)	15.47	15.82
EP (kg PO_4-equivalent)	11.65	11.76
GWP (kg CO_2-equivalent)	2 132	2 374
ODP (kg CFC-11-equivalent)	0.00017	0.00019
POP (kg C_2H_4-equivalent)	1.25	1.29
FAETP (kg 1.4-DB-equivalent)	1 430	1 436
HTP (kg 1.4-DB-equivalent)	621.7	639.9
MAETP (kg 1.4-DB-equivalent)	667 572	649 257
TETP (kg 1.4-DB-equivalent)	513.2	520.5

The results show that for most impact categories, such as abiotic depletion potential for elements (ADPe), acidification (AP) and eutrophication potential (EP), photochemical (POP) and human toxicity potential (HTP), or ecotoxicity potentials (freshwater (FAETP), marine (MAETP) and terrestrial (TETP)), there was no significant difference between summer and winter rotations environmental burden. For these impact categories, the differential between the summer and winter rotations was less than 10%.

The largest differences between summer and winter rotations were observed for three impact categories, abiotic depletion potential of fossil fuels (ADPf), global warming potential (GWP) and ozone layer depletion potential (ODP). These differences are clearly due to heating processes because of higher natural gas consumption.

For eight of the 11 impact categories, feed-related processes are the largest contributors to environmental burdens. Feeding is the most complex category, ranging from the cultivation and processing of fodder crops (maize, wheat, soya, rapeseed), the procurement and transport of additional minerals and vitamins, to the production of a finished feed mix in a feed mixing plant. The ADPf, ODP and MAETP impact categories are those where electricity consumption is the largest contributor to the environmental burden, rather than the feed processes.

3.1.2. Environmental impacts by producing CPPL compared to chemical fertilizers

3.1.2.1. Environmental impacts by producing 1 kg of CPPL and chemical fertilizers

The environmental impacts of the production of CPPL and the different chemical fertilizers were first evaluated per 1 kg of end product. Among the N-fertilizers, the fertilizers ammonium nitrate (AN), calcium ammonium nitrate (CAN) and urea were included in the study, among the P-fertilizers, the fertilizers triple superphosphate (TSP) and monoammonium phosphate (MAP) were included, and among the K-fertilizers, the fertilizer potassium chloride (KCl) was included (Table 3).

Table 3.

Emissions from the production of products per 1 kg of end product

Hatáskategória	**CPPL**	**AN**	**CAN**	**Karbamid**	**TSP**	**MAP**	**KCl**
ADPe (kg Sb-equivalent)	7.57x10^{-8}	6.47x10^{-6}	6.37x10^{-6}	7.43x10^{-6}	4.10x10^{-7}	6.70x10^{-6}	4.76x10^{-6}
ADPf (MJ)	0.269	18.338	14.941	27.107	13.987	8.898	4.121
AP (kg SO$_2$-equivalent)	0.024	0.006	0.005	0.005	0.010	0.003	0.002
EP (kg PO$_4$-equivalent)	0.005	0.002	0.002	0.002	0.004	0.002	0.001
GWP (kg CO$_2$-equivalent)	0.273	1.382	1.137	1.127	0.657	0.826	0.399
ODP (kg CFC-11-equivalent)	3.48x10^{-8}	1.50x10^{-7}	1.23x10^{-7}	2.25x10^{-7}	1.01x10^{-7}	8.54x10^{-8}	3.73x10^{-8}
POP (kg C$_2$H$_4$-equivalent)	2.87x10^{-5}	1.35x10^{-4}	1.17x10^{-4}	1.95x10^{-4}	4.29x10^{-4}	1.32x10^{-4}	7.97x10^{-5}
FAETP (kg 1.4-DB-equivalent)	0.028	0.274	0.256	0.314	0.198	0.362	0.188
HTP (kg 1.4-DB-equivalent)	0.032	0.449	0.429	0.534	0.172	0.502	0.334
MAETP (kg 1.4-DB-equivalent)	47.419	663.080	616.340	790.531	523.135	833.587	504.535
TETP (kg 1.4-DB-equivalent)	3.14x10^{-4}	1.51x10^{-3}	1.46x10^{-3}	1.82x10^{-3}	5.08x10^{-3}	6.48x10^{-3}	8.61x10^{-4}

The value of abiotic depletion potential for elements (ADPe) was highest for the production of nitrogen fertilizers (AN, CAN, urea) and MAP, and lowest for CPPL. Among the chemical fertilizers, ADPe was lowest during the production of 1 kg TSP. It is likely that the abiotic depletion potential of TSP was the lowest among the fertilizers because, similar to CPPL, electricity consumption was the largest contributing energy stream to emissions, while the generation (CPPL) or extraction (TSP) of raw materials was only the second largest contributor. In contrast, for the other chemical fertilizers, the extraction of raw materials or mining infrastructure was the primary contributor.

The value of abiotic depletion potential of fossil fuels (ADPf) in MJ was also lowest during the production of CPPL. For CPPL, three processes are the main contributors to emissions, polyethylene production (for packaging) and electricity and fuel consumption. After CPPL, KCl fertilizer had the lowest emissions, but its estimated emissions were also about fifteen times higher than CPPL. For this product, steam production was the largest contributor to emissions, followed to a lesser extent by extraction and processing of raw materials, polyethylene production and electricity consumption. The highest value was produced by urea production, with emissions around 100 times higher than CPPL. For N fertilizer production, natural gas consumption was the most polluting process, while for TSP it was raw material extraction and steam production, and for MAP it was steam production, natural gas and electricity consumption.

Only two of the impact categories, acidification potential (AP) and eutrophication potential (EP), had higher emissions when producing CPPL. The value of AP ranges between 0.002 and 0.01 kg SO_2 equivalent/kg product, regardless of the type of fertilizer. The lowest emission was observed for KCl fertilizer and the highest emission was observed for TSP among the fertilizers. For the former, the largest contributing processes were steam production and extraction and processing of raw materials (due to SO_2), and for the latter, H_2SO_4 production. CPPL produced 93% more emissions than KCl and 58% more emissions than TSP. For CPPL, NH_3 emissions due to manure processing are responsible for the high acidification potential value. For AN and CAN fertilizers, HNO_3 production (NH_3 and $NO_\times$), for urea, steam production and raw material extraction and processing (SO_2 and NH_3), and for MAP, electricity consumption and raw material extraction (SO_2 and NH3$_)$ were the processes contributing to AP.

Similar trends were observed for emissions in terms of eutrophication potential. Also, for this impact category, emissions were lowest for KCl fertilizer and highest for TSP. In both cases, emissions were caused by the extraction and processing of raw materials, due to the emission of phosphate and phosphorus into water. For CPPL production, the eutrophication potential was 0.0054 kg PO4-equivalent, which is 88% higher for the former fertilizer and 24% higher for the latter. In this case, NH_3 and N_2O emissions during broiler manure processing and electricity consumption were the contributors to the high environmental load. For the other manures, the contributing processes were similar to those for acidification potential. For AN and CAN fertilizers, HNO_3 production (NH_3 and $NO_\times$) and for urea and MAP, extraction and processing of raw materials (PO_4, NH_3) were the contributing processes of EP.

The value of global warming potential (GWP) was lowest at CPPL. Contributing to emissions were electricity consumption (CO_2 and CH_4), broiler manure processing (N_2O and CH_4), fuel consumption (CO_2) and further treatment of waste generated (CO_2). Among chemical fertilizers, the production of KCl was again the lowest. The highest emissions were for N fertilizers, with ammonium nitrate being the most important. The production of AN was five times more polluting than the production of CPPL. For fertilizers, CO_2 and CH_4 emissions from the production of steam for fertilizer production were almost equally responsible for the high GWP.

The value of ozone layer depleting potential (ODP) was lowest for KCl and highest for urea (sixfold difference) among the chemical fertilizers. While for KCl C_2H_6 and CH_4 emissions from steam production and raw material processing contributed to ODP, for urea CH_4 emissions from natural gas consumption contributed to ODP, as for the other two N fertilizers. Besides urea, emissions were also high during the production of CAN and MAP. These values were on average fifteen times higher than those observed for CPPL. At TSP, the main ODP contributing processes were raw material extraction (CH_4) and steam production (CH_4 and C_2H_6), at CPPL electricity and fuel consumption and CH_4 and C_2H_6 emissions during the processing of broiler chicken manure.

The photochemical oxidation potential (POP) was lowest among the fertilizers during KCl production and highest for TSP (fivefold difference), as were acidification and eutrophication potentials. For CPPL, electricity and fuel consumption as well as polyethylene production contributed to POP due to CO and SO_2 emissions, while for fertilizers, raw material extraction and processing and natural gas consumption were the typical contributing processes.

The production of KCl fertilizer also had the lowest emissions in terms of fresh water aquatic (seven times the CPPL), marine aquatic (eleven times the CPPL) and terrestrial ecotoxicity potential (three times the CPPL). For the same impact categories, the largest emissions were from the production of MAP. Compared to the CPPL, the emissions from the production of MAP were thirteen times the freshwater ecotoxicity potential (FAETP), eighteen times the marine ecotoxicity potential (MAETP) and twenty-one times the terrestrial ecotoxicity potential (TETP). At CPPL, electricity consumption, waste treatment processes and broiler chicken manure handling contribute to these impact categories. For fertilizers, the typical contributing processes are rather raw material extraction, processing, electricity consumption, steam production and natural gas consumption.

Human toxicity potential (HTP) was lowest for TSP. Urea produced the highest value of emissions. In the production of fertilizers, the extraction and production of raw materials themselves, as well as electricity consumption and steam production, were the typical contributing processes, mainly due to Cr emissions. Emissions of TSP were five times and urea about 17 times higher than CPPL, with electricity consumption, waste treatment and emissions during broiler chicken manure processing contributing to HTP.

3.1.2.2. Environmental impacts by producing of 1 kg of active substance

After establishing and evaluating the environmental impacts per 1 kg of product, I evaluated the values of the different impact categories per 1 kg of active substance, separately for 1 kg of N, 1 kg of P_2O_5 and 1 kg of K_2O.

Environmental impacts by producing of 1 kg of the nitrogen active substance

The environmental impacts during the production of the CPPL product were compared with the emissions from the production of the most commonly used N fertilizers - ammonium nitrate (AN), calcium ammonium nitrate (CAN) and urea - per kg of N active substance (Table 4).

Table 4.

Impact assessment of the production of 1 kg of nitrogen active substance

Impact categories	**CPPL (5,5% N)**	**AN (33,5% N)**	**CAN (27% N)**	**Karbamid (46% N)**
ADPe (kg Sb-equivalent)	1.38×10^{-6}	9.06×10^{-6}	2.36×10^{-5}	1.61×10^{-5}
ADPf (MJ)	4.883	54.831	55.283	58.822
AP (kg SO_2-equivalent)	0.439	0.019	0.019	0.010
EP (kg PO_4-equivalent)	0.0989	0.0065	0.007	0.0038
GWP (kg CO_2-equivalent)	4.955	4.133	4.208	2.445
ODP (kg CFC-11-equivalent)	6.33×10^{-7}	4.48×10^{-7}	4.57×10^{-7}	4.88×10^{-7}
POP (kg C_2H_4-equivalent)	5.23×10^{-4}	4.04×10^{-4}	4.32×10^{-4}	4.23×10^{-4}
FAETP (kg 1.4-DB-equivalent)	0.518	0.819	0.947	0.681
HTP (kg 1.4-DB-equivalent)	0.586	1.341	1.588	1.158
MAETP (kg 1.4-DB-equivalent)	862.070	1982.609	2280.459	1715.452
TETP (kg 1.4-DB-equivalent)	0.0063	0.0045	0.0046	0.0049

For six out of 11 impact categories, CPPL produced higher emission values (AP, EP, GWP, ODP, POP, TETP) than N fertilizers. But it is important to note the N content of each product and look at emissions in that way. For example, if we want to apply 1 kg of N with CPPL, we need 18.18 kg of poultry manure if we calculate with a N content of 5.5% in CPPL. In contrast, we only need 2.99 kg of ammonium nitrate (33.5% N content), 3.7 kg of CAN (27% N content) and 2.17 kg of urea (46% N content) for 1 kg N.

Environmental impacts by producing of 1 kg of the phosphate active substance

The comparison of CPPL with triple superphosphate (TSP) and monoammonium phosphate (MAP) was based on 1 kg of P_2O_5 (Table 5).

Table 5.

Impact assessment of the production of 1 kg of phosphate active substance

Impact categories	**CPPL (3% P_2O_5)**	**TSP (46% P_2O_5)**	**MAP (52% P_2O_5)**
ADPe (kg Sb-equivalent)	2.52×10^{-6}	8.90×10^{-7}	1.29×10^{-5}
ADPf (MJ)	8.95	30.35	17.09
AP (kg SO_2-equivalent)	0.804	0.022	0.007
EP (kg PO_4-equivalent)	0.18	0.01	0.003
GWP (kg CO_2-equivalent)	9.08	1.43	1.59
ODP (kg CFC-11-equivalent)	1.16×10^{-6}	2.20×10^{-7}	1.64×10^{-7}
POP (kg C_2H_4-equivalent)	0.0010	0.0009	0.0003
FAETP (kg 1.4-DB-equivalent)	0.95	0.43	0.69
HTP (kg 1.4-DB-equivalent)	1.07	0.37	0.97
MAETP (kg 1.4-DB-equivalent)	1580.46	1135.20	1600.49
TETP (kg 1.4-DB-equivalent)	0.0105	0.0110	0.0124

For most of the impact categories, the two P fertilizers produced the lowest emissions. However, as mentioned for the N fertilizers, the amount of fertilizer needed to apply 1 kg of active ingredient has to be taken into consideration.

In this case, the P_2O_5 content of CPPL is 3%, so for 1 kg of P_2O_5 active substance, 33.33 kg of CPPL must be applied. In contrast, 2.17 kg of TSP with 46% P_2O_5 is sufficient to apply 1 kg of active ingredient, and only 1.92 kg of MAP with 52% P_2O_5. Thus, 15 times (compared to TSP) and 17 times (compared to MAP) more raw material from CPPL is needed to process 1 kg of P_2O_5 active substance.

Environmental impacts by producing 1 kg of potassium active substance

The pollutants emitted during the production of CPPL and KCl fertilizer were also compared on the basis of the active substance K.

Based on the results shown in Table 6, only the abiotic depletion potential for elements (ADPe) showed lower values of emissions for CPPL production compared to KCl fertilizer production. For the other impact categories, the emissions per kg K2O active substance were always more favourable for KCl fertilizer than for CPPL.

Table 6.

Impact assessment of the production of 1 kg of the potassium active substance

Impact categories	**CPPL (2.5% K_2O)**	**KCl (60% K_2O)**
ADPe (kg Sb-equivalent)	3.03×10^{-6}	7.90×10^{-6}
ADPf (MJ)	10.74	6.84
AP (kg SO_2-equivalent)	0.97	0.003
EP (kg PO_4-equivalent)	0.22	0.001
GWP (kg CO_2-equivalent)	10.90	0.66
ODP (kg CFC-11-equivalent)	1.39×10^{-6}	6.19×10^{-8}
POP (kg C_2H_4-equivalent)	0.001	0.0001
FAETP (kg 1.4-DB-equivalent)	1.14	0.31
HTP (kg 1.4-DB-equivalent)	1.29	0.55
MAETP (kg 1.4-DB-equivalent)	1896.7	837.5
TETP (kg 1.4-DB-equivalent)	0.013	0.001

However, as in the case of emissions per kg N and P_2O_5, K_2O is also present in the chemical fertilizer in much higher concentrations than in the CPPL. While the K_2O content of CPPL is 2.5%, the KCl fertilizer contains 60%. So, to apply 1 kg of K_2O with CPPL, 40 kg of CPPL fertilizer is needed. In contrast, only 1.66 kg of KCl fertilizer is needed to apply 1 kg of K_2O.

3.1.2.3. Environmental impacts of a medium-sized farm's (100 hectare) nutrient replenishment

The environmental impact of nutrient supply to a 100 hectares field was also assessed. The amount of CPPL to be applied was set at 1.5 t/ha as suggested by Baromfi-Coop Ltd. and SZABÓ et al. (2019). This amount of CPPL applied corresponds to 82.5 kg N/ha which is in line with the recommendation of KÁTAI et al. (2021) that 80 kg N/ha is the minimum N requirement for soils with low to medium N supply. The amount of chemical fertilizers to be applied was determined, according to the active ingredient content of CPPL at a dose of 1.5 t/ha and then different chemical fertilizer combinations were established.

The environmental impacts of the CPPL and the six fertilizer combinations were calculated using the previously determined environmental impacts of 1 kg of end product (Table 3). The environmental impacts were then classified into three categories (low, medium and high). The three categories were defined by dividing the difference between the maximum and minimum values for each impact category into three equal intervals.

The emissions of pollutants during the production of the amount to be applied were summarised for each category (Table 7).

The abiotic depletion potential for elements (ADPe) at 150 t CPPL is 0.01 kg Sb-equivalent. For chemical fertilizers, 0.17 kg Sb-equivalent was the lowest emission for the NPK5 group and 0.25 kg Sb-equivalent was the highest for NPK2. The production of 100 ha of NPK fertilizers on average results in 95% higher emissions than this impact category.

Table 7.

Environmental emissions generated by the production of the applied CPPL and NPK treatments on 100 hectares of arable land

Impact categories	**CPPL**	**NPK1**	**NPK2**	**NPK3**	**NPK4**	**NPK5**	**NPK6**
ADPe (kg Sb-equivalent)	0.011	0.193	0.227	0.228	0.257	0.167	0.205
ADPf (MJ)	40290	614640	496928	618834	500097	648453	529320
AP (kg SO_2-equivalent)	3620	262.9	173.3	265.3	175.3	196.0	115.6
EP (kg PO_4-equivalent)	816.1	98.7	65.8	101.0	67.7	75.8	46.1
GWP (kg CO_2-equivalent)	40880	43005	39357	43654	39886	29113	27372
ODP (kg CFC-11-equivalent)	0.0052	0.0049	0.0042	0.0050	0.0043	0.0053	0.0045
POP (kg C_2H_4-equivalent)	4.31	8.02	4.54	8.25	4.74	8.18	4.71
FAETP (kg 1.4-DB-equivalent)	4270	9862	10192	10923	11109	8731	9241
HTP (kg 1.4-DB-equivalent)	4833	14818	16069	16868	17841	13323	14823
MAETP (kg 1.4-DB-equivalent)	$7.11x10^{6}$	$2.46x10^{7}$	$2.46x10^{7}$	$2.71x10^{7}$	$2.67x10^{7}$	$2.24x10^{7}$	$2.28x10^{7}$
TETP (kg 1.4-DB-equivalent)	47.06	92.30	93.98	99.47	100.18	87.60	90.08

Green = low environmental impact; yellow = medium environmental impact; red = high environmental impact.
NPK1 = AN + TSP + KCl (40.45 t/100 ha); NPK2 = AN + MAP + KCl (36.35 t/100 ha); NPK3 = CAN + TSP + KCl (46.15 t/100 ha); NPK4 = CAN + MAP + KCl (41.51 t/100 ha); NPK5= urea + TSP + KCl (33.85 t/100 ha); NPK6 = urea + MAP + KCl (30.59 t/100 ha)

The value of abiotic depletion potential for fossil fuels (ADPf) emissions were also lowest at CPPL, with emissions averaging 93% higher for different combinations of chemical fertilizers. Acidification potential (AP) and eutrophication potential (EP), on the other hand, were higher in the production of CPPL. Acidification potential had on average 94% lower emissions for NPK fertilizers and eutrophication potential had on average 90% lower emissions. A possible reason for this, based on DE VRIES et al. (2012), is that NH_3 and N_2O emissions contribute to the high acidification potential and NO_3 and PO_4 emissions to the eutrophication potential.

The value of global warming potential (GWP) was on average 5.5% lower for 150 t of CPPL compared to NPK1 and NPK3 combinations. Similar values to CPPL were found for NPK2 and NPK4 combinations, while the production of NPK5-6 fertilizer combinations, where the nitrogen fertilizer was urea, had 29-33% lower emissions. This can be explained by the fact that urea has the highest nitrogen content (46% N) of the nitrogen fertilizers studied, and therefore requires less production and application than combinations where the nitrogen source was AN or CAN.

The ozone depleting potential (ODP) is nearly the same for both CPPL and the different combinations of NPK fertilizers. These values range from 0.0047 to 0.005 kg CFC-11 equivalent.

The photochemical oxidation potential (POP) was highest in the categories where the P2O5-active substance was supplied by TSP (NPK1, NPK3, NPK4). For these scenarios, the value of POP was 47% higher than CPPL production. Where the phosphorus fertilizer was MAP, emissions were 15% higher compared to CPPL.

For the impact categories expressed in kg 1,4-DB equivalent (freshwater aquatic ecotoxicity potential, marine aquatic ecotoxicity potential, human toxicity potential and terrestrial ecotoxicity potential), the emission rates are almost similar. For the freshwater aquatic ecotoxicity potential (FAETP), the emissions for fertilizers ranged from 8731 to 12122 kg 1,4-DB equivalent/NPK, which is 51 to 65% higher than the amount of the pollutant released during the production of CPPL. The human toxicity potential (HTP) for 150 t CPPL is 4833 kg 1,4-DB equivalent/NPK, while the emission rate during fertilizer production is on average 70% higher. A similar pattern of emissions is observed for the marine aquatic ecotoxicity potential (MAETP). On average, emissions from CPPL production are 72% lower than from different combinations of NPK fertilizers. The terrestrial ecotoxicity potential (TETP) for fertilizers ranges from 87.6 to 105.95 kg 1.4-DB-equivalent. On average, emissions from fertilizers are 50% higher than the value determined for CPPL.

Overall, the values shown in Table 7 indicate that the production of CPPL has a lower environmental impact (7 out of 11 impact categories belong to the "low environmental impact" group) than the production of chemical fertilizers containing equivalent macro-nutrients. Of the six chemical fertilizer combinations, NPK5 had the lowest environmental load, while NPK1-4 combinations had the highest, where the nitrogen fertilizers were AN and CAN.

3.1.3. Environmental impacts of crop production

In Tables 8-9, the results of the crop productions' life cycle assessment are presented for 1 tonne of maize and winter wheat, depending on whether nutrient addition was done with CPPL or with different chemical fertilizer combinations.

For maize, out of the 11 impact categories, only ODP had higher emissions than application of CPPL, the other ten impact categories always had lower emissions compared to NPK combinations (Table 8). In the life-cycle assessment of winter wheat cultivation technology, seven of the 11 impact categories (ADPe, ADPf, GWP, POP, FAETP, HTP, MAETP) clearly showed lower environmental pressures in the scenarios where nutrient replenishment was done with CPPL per 1 tonne of winter wheat yield (Table 9). AP and ODP were higher for the CPPL application, while EP and TETP showed similar results for both CPPL and chemical fertilizer combinations.

For the ADPe impact category, the main contributors were the fuel use and transport processes in the maize production (Table 8), while in wheat production the contribution of pesticides was also significant (Table 9) in the application of CPPL. For the NPK combinations, the extraction and production of raw materials for chemical fertilizers were the main contributors to the environmental impact, followed by fuel use, regardless of whether maize or wheat was grown. At ADPf, both for maize and winter wheat production with CPPL and chemical fertilizers, the most environmentally damaging processes are related to fuel and electricity consumption.

Table 8.

Life-cycle assessment of maize (1 t) production with different nutrient additives

Impact categories	CPPL	NPK1	NPK2	NPK3	NPK4	NPK5	NPK6
ADPe (kg Sb-eq)	$1,53\times10^{-3}$	$1,77\times10^{-3}$	$1,82\times10^{-3}$	$1,82\times10^{-3}$	$1,87\times10^{-3}$	$1,74\times10^{-3}$	$1,79\times10^{-3}$
ADP (MJ)	4857	5571	5443	5571	5443	5643	5486
AP (kg SO$_2$-eq)	9,06	15,28	15,19	15,28	15,19	15,2	15,11
EP (kg PO$_4$-eq)	8,79	10,46	10,42	10,47	10,42	10,44	10,39
GWP (kg CO$_2$-eq)	644,7	928,4	924,5	928,6	926	975,5	972,9
ODP (kg CFC-11-eq)	$1,56\times10^{-4}$	$1,54\times10^{-4}$	$1,53\times10^{-4}$	$1,54\times10^{-4}$	$1,53\times10^{-4}$	$1,54\times10^{-4}$	$1,53\times10^{-4}$
POP (kg C$_2$H$_4$-eq)	0,071	0,079	0,076	0,08	0,076	0,08	0,076
FAETP (kg 1.4-DB-eq)	175,9	183	183,9	184,5	185,6	181,8	182,5
HTP (kg 1.4-DB-eq)	303,2	317,8	319,9	320,3	322,6	316	317,9
MAETP(kg 1.4-DB-eq)	160000	182857	184286	185714	187143	180000	181429
TETP (kg 1.4-DB-eq)	2,30	2,36	2,36	2,37	2,37	2,35	2,35

Green = low environmental impact; yellow = medium environmental impact; red = high environmental impact.
NPK1 = AN + TSP + KCl (40.45 t/100 ha); NPK2 = AN + MAP + KCl (36.35 t/100 ha); NPK3 = CAN + TSP + KCl (46.15 t/100 ha); NPK4 = CAN + MAP + KCl (41.51 t/100 ha); NPK5= urea + TSP + KCl (33.85 t/100 ha); NPK6 = urea + MAP + KCl (30.59 t/100 ha)

For the AP, EP and GWP impact categories, the processes that contributed most to emissions were similar for both maize and wheat. For crops production with CPPL, the main contributors to environmental pressures are field operations and fuel use, while for fertilizer crops, emissions from fertilizer production, extraction and application, especially N fertilizers, are also significant contributors.

The values of ODP were also highest when nutrient supplementation was done with CPPL in maize and wheat production also. In this impact category the largest contributors were the fuel and electricity consumption, and pesticide use. Fuel use and pesticides, as well as the use of heavy machinery in field operations, were also contributors to POP.

Table 9.

Life-cycle assessment of winter wheat (1 t) production with different nutrient additives

Impact categories	CPPL	NPK1	NPK2	NPK3	NPK4	NPK5	NPK6
ADPe (kg Sb-eq)	4,46×10^{-4}	6,59×10^{-4}	7,01×10^{-4}	6,94×10^{-4}	7,44×10^{-4}	6,33×10^{-4}	6,71×10^{-4}
ADP (MJ)	777,5	1387,5	1262,5	1362,5	1275	1450	1300
AP (kg SO_2-eq)	4,21	4,10	4,01	4,09	4,01	4,02	3,94
EP (kg PO_4-eq)	3,34	3,36	3,32	3,36	3,33	3,34	3,29
GWP (kg CO_2-eq)	233,78	271,02	266,53	270,12	268,36	264,91	262,03
ODP (kg CFC-11-eq)	2,00×10^{-5}	1,88×10^{-5}	1,75×10^{-5}	1,75×10^{-5}	1,75×10^{-5}	1,88×10^{-5}	1,75×10^{-5}
POP (kg C_2H_4-eq)	0,012	0,019	0,016	0,019	0,016	0,019	0,016
FAETP (kg 1.4-DB-eq)	191,91	197,88	198,78	199,33	200,39	197,07	197,65
HTP (kg 1.4-DB-eq)	45,17	56,36	58,3	58,64	60,95	55,14	56,63
MAETP (kg 1.4-DB-eq)	29250	48500	49750	51625	53250	47125	47500
TETP (kg 1.4-DB-eq)	77,82	77,87	77,87	77,87	77,80	77,86	77,87

Green = low environmental impact; yellow = medium environmental impact; red = high environmental impact.
NPK1 = AN + TSP + KCl (40.45 t/100 ha); NPK2 = AN + MAP + KCl (36.35 t/100 ha); NPK3 = CAN + TSP + KCl (46.15 t/100 ha); NPK4 = CAN + MAP + KCl (41.51 t/100 ha); NPK5= urea + TSP + KCl (33.85 t/100 ha); NPK6 = urea + MAP + KCl (30.59 t/100 ha)

In maize production, HTP and FAETP were contributed by field operations, electricity consumption and pesticide use, the latter two for MAETP and electricity consumption and field operations for TETP. For wheat production, these were also the main contributing activities for the four impact categories mentioned above, plus the production of fertilizer and the raw materials for fertilizer production are also included to the contributors.

Overall, at the crop production processes should significantly reduce the use of pesticides and fertilizers in order to achieve sustainability and reduce environmental impacts. The introduction and use of reduced tillage systems can reduce fossil fuel use and GHG emissions from fuel use. The results shown can be important for improving good practices in crop production, even in support of policy decisions, thereby reducing environmental problems such as GHG emissions and air pollution.

3.2. COMPARISON OF THE EFFECTS OF CPPL AND AMMONIUM NITRATE IN POT EXPERIMENT

The mean values per treatment, with standard deviation and statistical group are shown in Tables 10-12. For ease of clarity, values where a significant increase over the control was observed at 5% significance level are marked in green, and where a significant decrease was observed, values are marked in blue. The treatments had a stimulating effect on maize compared to the control for most parameters (stem growth, germination parameters (germination % and

Vigour index), chlorophyll and carotenoid content), even if the increase was not statistically detectable in all cases. Table 10 summarizes the results obtained in the maize pot experiment.

Table 10.

Comparison of the effects of CPPL and AN on maize (*Zea mays* L.) growth parameters

Treatments	Root length (cm)	Stem length (cm)	Plant length (cm)	Dry matter content (%)	Germination %	Vigour-index	Chlorophyll content (µg/g)	Carotenoid content (µg/g)
Control	29.60^{a*} ± 11.69	25.00^{b} ± 6.29	54.60^{a} ± 16.69	18.80^{ab} ± 3.72	100^{a}	5479.13^{b} ± 1526.64	1457.34^{b} ± 395.23	267.96^{b} ± 65.65
CPPL 1 t/ha	26.83^{ab} ± 7.98	🟩 31.56^{a**} ± 7.26	58.93^{a} ± 13.56	19.02^{a} ± 5.42	128.5^{a} ± 16.49	🟩 8824.29^{a} ± 1663.82	1804.92^{ab} ± 264.45	323.6^{ab} ± 44.99
CPPL 1,5 t/ha	28.27^{ab} ± 5.98	🟩 32.74^{a} ± 6.90	61.01^{a} ± 11.31	18.59^{ab} ± 1.79	121.4^{a} ± 27.35	🟩 8155.71^{a} ± 675.59	1851.51^{ab} ± 543.39	328.93^{ab} ± 92.59
AN 320 kg/ha	26.86^{ab} ± 5.42	🟩 36.20^{a} ± 4.39	63.01^{a} ± 7.29	15.56^{b} ± 2.60	128.5^{a} ± 16.49	7672.14^{ab} ± 1087.44	🟩 2163.13^{a} ± 432.76	🟩 390.5^{a} ± 71.83
AN 500 kg/ha	🟦 22.66^{b***} ± 3.38	🟩 34.83^{a} ± 4.54	57.49^{a} ± 5.86	16.77^{b} ± 1.36	128.5^{a} ± 16.49	7102.86^{ab} ± 1400.35	2006.72^{ab} ± 177.26	342.49^{ab} ± 26.77

* Different letters indicate a significant difference between treatments at the $p<0.05$ level, based on Duncan's test. Where multiple letter indices are included, the separation of treatments is uncertain at 5% significance level.

** Green colour: significant increase compared to control.

*** Blue colour: significant decrease compared to control.

The differences between CPPL and AN fertilizer were not significant, and the separation of treatments was not clear at 5% significance level. However, higher values for root length, dry matter content and Vigour index were also measured in the CPPL treatments, despite the fact that the N applied with CPPL was half that applied with AN.

Table 11 summarizes the results obtained in the winter wheat pot experiment.

Table 11.

Comparison of the effects of CPPL and AN on winter wheat growth parameters

Treatments	Root length (cm)	Stem length (cm)	Plant length (cm)	Dry matter content (%)	Germination %	Vigour-index	Chlorophyll content (µg/g)	Carotenoid content (µg/g)
Control	20.55^{a*} ± 7.969	24.21^{b} ± 8.124	44.76^{ab} ± 14.74	20.98^{a} ± 6.056	100^{ab}	4532.65^{a} ± 1180.33	1769.65^{a} ± 235.476	294.56^{b} ± 63.309
CPPL 1 t/ha	🟦 15.50^{c} ± 5.752	24.37^{b} ± 4.039	39.97^{b} ± 6.224	16.70^{ab} ± 1.980	108.11^{a} ± 0.000	4321.08^{a} ± 191.791	1759.25^{a} ± 92.350	268.91^{b} ± 36.864
CPPL 1,5 t/ha	18.48^{ab} ± 5.079	🟩 27.47^{a} ± 5.657	45.96^{a} ± 8.937	🟦 15.34^{b} ± 1.348	105.41^{a} ± 5.405	4857.22^{a} ± 571.934	1888.73^{a} ± 375.94	352.695^{ab} ± 77.045
AN 320 kg/ha	🟦 11.96^{d} ± 6.477	22.18^{b} ± 10.145	🟦 34.14^{c} ± 15.548	🟦 13.79^{b} ± 3.649	91.89^{b} ± 6.242	🟦 3148.19^{b} ± 478.901	1944.90^{a} ± 263.647	318.38^{ab} ± 33.22
AN 500 kg/ha	🟦 17.29^{b} ± 5.023	🟩 27.99^{a} ± 5.482	45.28^{ab} ± 8.841	🟦 13.90^{b} ± 2.776	105.41^{a} ± 5.405	4793.19^{a} ± 760.485	2179.65^{a} ± 351.129	🟩 401.67^{a} ± 82.513

* Different letters indicate a significant difference between treatments at the $p<0.05$ level, based on Duncan's test. Where multiple letter indices are included, the separation of treatments is uncertain at 5% significance level.

** Green colour: significant increase compared to control.

*** Blue colour: significant decrease compared to control.

Overall, the results for winter wheat showed higher values than the control for the higher doses of CPPL and AN fertilizer applied, but for most parameters, the increase could not be significantly confirmed. There was no significant difference between the effect of CPPL and AN fertilizer.

Table 12 summarizes the results obtained in the sunflower pot experiment.

Table 12.

Comparison of the effects of CPPL and AN on sunflower growth parameters

Treatments	Root length (cm)	Stem length (cm)	Plant length (cm)	Dry matter content (%)	Germination %	Vigour-index	Chlorophyll content (µg/g)	Carotenoid content (µg/g)
Control	9.25^{ab*} ± 3.790	14.57^{b} ± 4.537	23.81^{b} ± 7.566	7.35^{b} ± 1.744	100^{a}	2403.05^{ab} ± 550.327	557.89^{a} ± 211.61	116.68^{a} ± 46.489
CPPL 1 t/ha	9.99^{a} ± 3.262	17.28^{a**} ± 1.954	27.27^{a} ± 4.195	11.47^{a} ± 4.154	108.11^{a} ± 0.000	2947.84^{a} ± 137.699	655.21^{a} ± 62.76	137.41^{a} ± 13.928
CPPL 1,5 t/ha	8.79^{ab} ± 3.237	13.96^{b} ± 5.741	22.75^{b} ± 8.167	6.68^{b} ± 1.145	100.00^{a} ± 10.351	2284.95^{b} ± 385.054	511.08^{a} ± 133.21	110.21^{a} ± 27.278
AN 320 kg/ha	8.84^{ab} ± 2.832	14.77^{b} ± 2.894	23.61^{b} ± 4.431	6.77^{b} ± 0.755	108.11^{a} ± 0.000	2552.43^{ab} ± 233.168	572.10^{a} ± 70.739	113.87^{a} ± 6.117
AN 500 kg/ha	8.19^{b***} ± 3.492	14.47^{b} ± 5.481	22.66^{b} ± 8.026	7.13^{b} ± 1.843	100.00^{a} ± 10.351	2279.57^{b} ± 464.95	464.42^{a} ± 55.659	97.03^{a} ± 13.363

* Different letters indicate a significant difference between treatments at the $p<0.05$ level, based on Duncan's test. Where multiple letter indices are included, the separation of treatments is uncertain at 5% significance level.

** Green colour: significant increase compared to control.

Overall, the results obtained for sunflower showed that it responded best to the lower dose of CPPL, but the plant was also stimulated by the lower dose of AN fertilizer. However, for the treatments with higher doses of CPPL and AN fertilizer, the values did not exceed those of the control for any of the parameters.

4. NEW SCIENTIFIC RESULTS OF THE THESIS

1. The environmental impact of 1 t broiler chicken production was quantified using an LCA approach for summer and winter rotations. The quantified environmental impacts are used as reference data for the assessment of the environmental pressures of 1 t broiler chicken production in Hungary and Central Europe, as literature on this topic is limited. The share of feeding as the main process contributing to the environmental impacts for 3 main impact categories is: AP: 81-83%, EP: 97-98%, GWP: 63-70%.

2. It was found that the environmental impact of the product produced by the Hosoya composting plant (CPPL) per kg of product is lower than that of fertilizers in nine out of 11 impact categories (ADPe, ADPf, GWP, ODP, HTP, POP, FAETP, MAETP, TETP), while the environmental impact of CPPL per kg of active ingredient (N, P_2O_5, K_2O) is higher than that of mono-element fertilizers.

3. It has been concluded that CPPL can be a suitable nutrient replacement alternative in terms of environmental impact, assuming complex NPK nutrient replacement. This is because the environmental burden of CPPL production is less than seven out of 11 impact categories (ADPe, ADPf, HTP, POP, FAETP, MAETP, TETP) and similar to the combined environmental burden of producing equivalent N, P_2O_5 and K_2O fertilizers (GWP, ODP) for two of them. Thus, CPPL can meet the EU Green Deal objectives to reduce the use of fertilizers.

4. It has been found that although the environmental burden of CPPL production is higher for N, P_2O_5 and K_2O separately, it is higher when nitrogen, phosphorus and potassium fertilizers are applied together, maize fertilized with CPPL already has a lower environmental impact based on 10 out of 11 impact categories (ADPe, ADPf, AP, EP, GWP, POP, HTP, FAETP, MAETP, TETP) compared to NPK combinations (e.g. GWP by 30-34%).

5. For the winter wheat scenario, it was also found that although the environmental burden of CPPL production is higher for N, P_2O_5 and K_2O separately, the environmental burden of CPPL production is higher for complex N-, P_2O_5 and K_2O, a forage crop with a lower environmental burden can be grown with CPPL, based on seven out of 11 impact categories (ADPe, ADPf, GWP, POP, HTP, MAETP, FAETP) (e.g.: 11-14% for GWP).

5. THE PRACTICAL USE OF THE RESULTS

1. Life cycle assessment can be used to evaluate the environmental impacts of circular broiler chicken production systems and identify critical points, providing information and decision support for improvement, modernisation and the development of more sustainable systems. According to the international literature, the feed processes (mainly due to fertilizer use and pesticides) have the greatest environmental impact. Greening feed production processes can therefore certainly reduce the environmental impact of broiler chicken production.

2. I first identified the material and energy flows of the Hosoya composting plant, which can serve as a methodological basis for assessing the environmental impacts of further Hosoya-type composting systems.

3. According to the results the environmental impact of fodder crop production can be significantly reduced by substitute NPK fertilizers with CPPL.

4. Based on the results observed in the pot experiment, the application of CPPL with complex active ingredient suggests a positive effect on the biomass of maize, winter wheat and sunflower plants compared to both control and AN fertilizer application on quicksand soils. The results are preliminary and field experiments are needed to confirm them.

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INTERNET2: https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0012.02/DOC_1&format=PDF

INTERNET3: www.openlca.org

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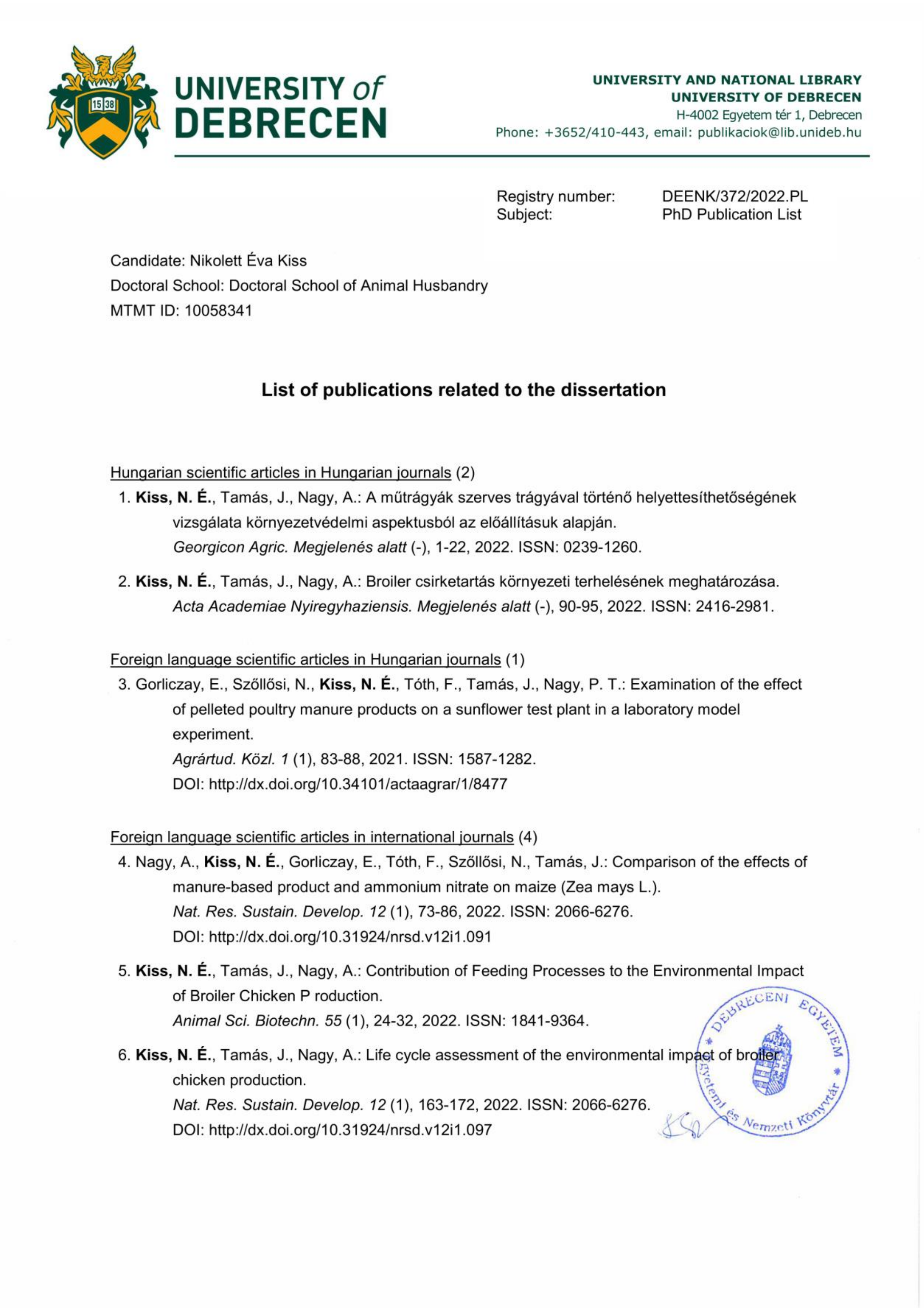

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List of publications related to the dissertation

Hungarian scientific articles in Hungarian journals (2)

1. **Kiss, N. É.**, Tamás, J., Nagy, A.: A műtrágyák szerves trágyával történő helyettesíthetőségének vizsgálata környezetvédelmi aspektusból az előállításuk alapján.
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3. Gorliczay, E., Szőllősi, N., **Kiss, N. É.**, Tóth, F., Tamás, J., Nagy, P. T.: Examination of the effect of pelleted poultry manure products on a sunflower test plant in a laboratory model experiment.
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