NIKOLETT ÉVA KISS[1], JÁNOS TAMÁS[1], ATTILA NAGY[116]

Life cycle assessment of composting and utilisation of broiler chicken manure

DOI: 10.29180/9786156342386_10

Abstract

The management and recycling of organic manure, which is generated in increasing quantities in fast-growing industries such as broiler chicken production, has become extremely significant. The European Union also encourages the application of organic fertilizers through the European Green Deal, which one of the aims to minimize chemical fertilizer use and increase the use of organic fertilizers.

In the present study, the treatment and application of broiler chicken manure was investigated from an environmental standpoint, using the life cycle assessment methodology (ISO 14040:2006) and including three impact categories (global warming potential (GWP), acidification potential (AP), eutrophication potential (EP)). In the first scenario, the environmental impact of the production of a composted and pelleted poultry litter (CPPL) product from a so-called Hosoya composting plant was evaluated. The environmental impact of producing CPPL in the amount necessary to supply a 100 ha area with nutrients was analysed, compared to the environmental impact of producing NPK fertilizer combinations (AN, CAN, urea, TSP, MAP, KCl) with the same active ingredient content. In the second scenario, the environmental impact on maize production was assessed when nutrient replenishment was carried out with CPPL and NPK fertilizer combinations.

Based on the results of the first scenario, the environmental impact of producing the CPPL is similar for GWP and higher for AP and EP than for the NPK fertilizer combinations. But need to considering that the same amount of NPK active substance requires a much larger amount of broiler chicken manure to be processed than the amount of chemical fertilizer to be produced. In contrast, in the second scenario a much lower environmental impact was already observed for GWP, AP and EP when the nutrient supplementation was done with CPPL in maize production.

Overall, the results indicate that CPPL can be viable alternative to chemical fertilizers, not just from an environmental standpoint but from financially due to continuously rising fertilizer prices.

Keywords: life cycle assessment, broiler chicken manure, Hosoya composting system, environmental impact

Introduction

The manure and other organic materials (e.g. compost, meat, bone and feather meal, etc.) that are not useful for livestock production technologies, can play an essential part in soil resource replenishment and even serve as a viable alternative to fertilizers (Moyo and Swanepoel, 2010; Mézes et al., 2015; Magnusson, 2016; He et al., 2016, 2020; Gorliczay et al., 2021). The issue of how to use the increased amount of manure has become increasingly important in recent years not only from an environmental but also from a circular economy perspective, thanks to fast-growing livestock sectors such as broiler farming (Chia et al., 2019; Nalunga et al., 2021). The livestock sectors are expected to become even more important in the future to meet the food needs of a growing population (Kasule et al., 2014; Enahoro et al., 2018; Van Harn et al., 2019; Janković et al., 2020).

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

[16]University of Debrecen, Faculty of Agricultural and Food Sciences and Environmental Management, Institute of Water and Environmental Management. 138. Böszörményi str. Debrecen, Hungary

Corresponding author e-mail address: kiss.nikolett@agr.unideb.hu

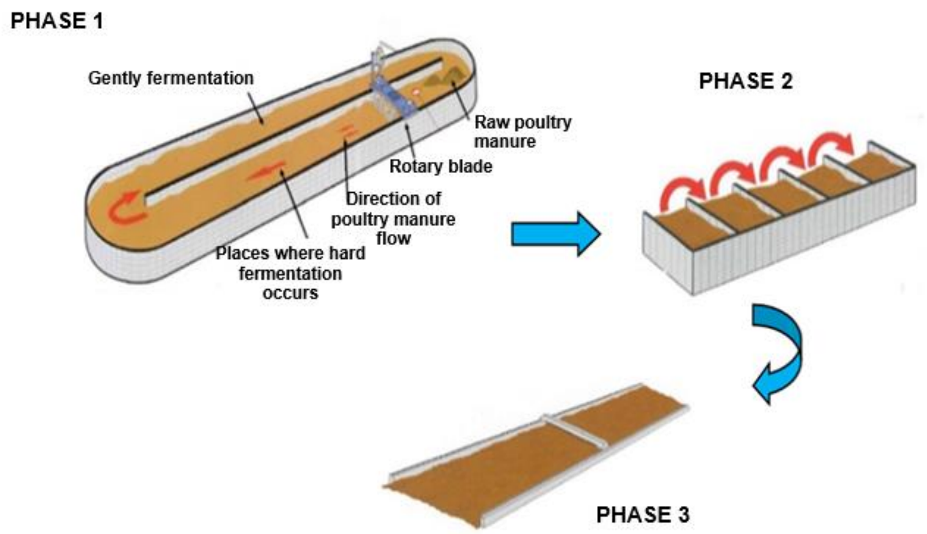
and less damaging to the environment. The European Union also introduced the European Green Deal (EU Green Deal) to comprehensively address environmental problems, with the main goal of making Europe climate neutral and sustainable by 2050 (Internet1). Among the objectives of the agreement concerning agriculture, the efforts to reduce the use of fertilizers and to favour the use of organic fertilizers are very important. Although fertilizers provide nutrients to vegetation quickly, in large quantities, and in easily accessible forms (Xiaoyu et al., 2013; Han et al., 2016; Bhatt et al., 2019; Versino et al., 2019; Gil-Ortiz et al., 2020), their use can have a number of negative environmental consequences. Excess fertilization, for example, increases the decomposition of soil organic matter, resulting in soil structure degradation, as well as polluting water bodies, resulting in leaching and acidification (Bíró et al., 1998; Savci, 2012; Gil-Ortiz et al., 2020; Messiga et al., 2020).

The most well-known form of manure recycling is material utilisation, which is not new because organic manures from animal husbandry have long been used as a nutrient replacement in crop production. In Hungary, until the first third of the 1900s, only manure was used to replace the nutrients taken up by plants, but due to intensive farming - and the introduction of fertilizers with higher active ingredient content - their use was pushed to the background. However, it is critical that organic manure be properly treated and disposed of before usage, as untreated manure is extremely harmful, containing numerous microorganisms that can pose animals and humans, as well as contaminate food and cause epidemics. Many foodborne diseases are associated to manure, either directly or indirectly, over the world (Garcia et al., 2010; Heredia and García, 2018). The issue of manure management is therefore becoming increasingly urgent not only from an environmental but also from a human health perspective. Due to the current uncertain fertilizer situation and high fertilizer prices, the substitution of fertilizers must now be considered from an economic standpoint in order to assure crop security.

One possible method of manure management is aerobic composting, which is a well-known and long-established method for the disposal of organic wastes and by-products (Filep, 1999; Modderman, 2020). Just a few literatures mention the composting of poultry manure, since poultry manure is rich in fibre and nitrogen and has a high moisture content, characteristics that are not conducive to composting. Georgakakis and Krintas (2000) mention two systems of Japanese origin, Okada and Hosoya, for composting by-products with these less favourable characteristics. In this research one of the scenarios is to investigate the environmental impact of this Hosoya composting system.

The technology covers a three-phase system consisting of two-phase aerobic fermentation and one-phase final drying (Figure 1). A granulate with a dry matter content of 80-85% is formed at the end of the process (Internet2; Csiba and Fenyvesi, 2012; Szabó, 2016), hereinafter CPPL (composted and pelletized poultry litter). The heat treatment removes toxic ammonia gases, weed seeds, and pathogenic microorganisms in the granulated goods acquired this way (Gaál, 2011).

Figure 1. Phases of the Hosoya composting system



A comparative analysis of the substitutability of fertilizers with CPPL was carried out based on the environmental burden of CPPL and fertilizer production and its application (crop production). The following fertilizers were included in the analysis: ammonium nitrate (AN), calcium ammonium nitrate (CAN), urea, triple superphosphate (TSP), monoammonium phosphate (MAP) and potassium chloride (KCl). As a research method, ISO14044:2006, "Environmental management. Life cycle assessment" was used for the analysis. Life cycle assessment is a suitable method for identifying and monitoring the main environmental pressures and critical points in the life cycle of a product.

Material and method

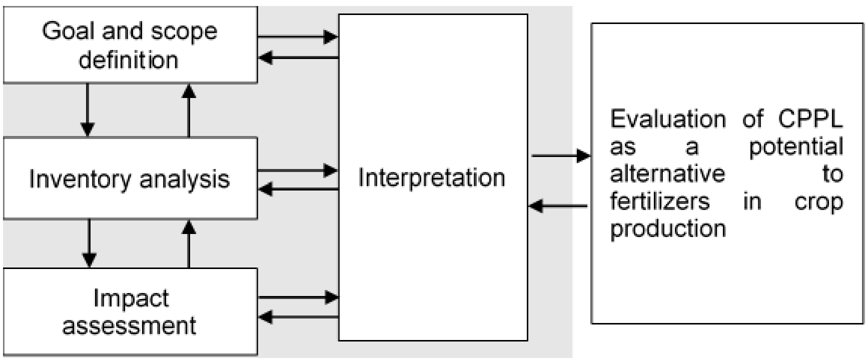
A life cycle assessment should be structured according to the following main steps, as recommended by the ISO 14040:2006 standard (Figure 2):

1. Definition of the goal and scope of LCA
2. Life Cycle Inventory Analysis
3. The Life Cycle Impact Assessment

Source: Internet3

4. Methods for the interpretation of LCA results

Figure 2. Steps of life cycle assessment (adopted from ISO14040:2006)



Definition of the goal and scope of LCA

The goal of the assessment, the scope (system boundaries), and the functional unit are all defined at the start of the life cycle assessment.

The goal of the life cycle assessment of the Hosoya composting plant

One of the goals of this study is to assess the role of CPPL as a potential chemical fertilizer alternative.

Environmental impacts during the production of CPPL in the Hosoya composting plant and during the production of chemical fertilizers should be identified and evaluated in order to provide a more accurate comparison. In this scenario, the environmental impacts of the amount of CPPL and chemical fertilizers needed to replenish the nutrients in a 100 ha field were assessed. Based on the suggestion of the product's manufacturer and Szabó et al. (2019) an application rate of 1.5 t/ha was calculated for CPPL. The amount of chemical fertilizers to be applied were calculated as a percentage of the 1.5 t/ha CPPL N, P_2O_5 and K_2O active substance content. To identify the system boundaries, only on-farm processes were considered.

The goal of the life cycle assessment of the maize production

Another goal of the study was to assess the environmental impact of 1 tonne of maize cultivation and to identify the critical points of cultivation technology. For this stage of the life cycle assessment, a scenario was considered where nutrient addition was either with 1.5 t/ha CPPL or with combinations of NPK fertilizers with the same active ingredient content of N, P_2O_5 and K_2O as 1.5 t/ha CPPL. 1 tonne of harvested maize served as the functional unit.

Life Cycle Inventory Analysis

The second step of the LCA is the life cycle inventory analysis, which quantifies the inputs and outputs that occur during the life cycle, which include raw materials and emissions.

The life cycle inventory analysis of the production of CPPL (Hosoya composting plant) and fertilizers

The composting plant provided some of the input data for the life cycle inventory assessment (manure and sludge, water, and fuel), while the rest was based on our own estimates (electricity, emissions). The quantities were first converted to one loading of a Hosoya tub based on the plant's data. Finally, based on the existing data, the values were converted to the material and energy flows needed to produce 1 kg of CPPL, for easier comparison later. These details were entered into the openLCA software, which was utilized to do the life cycle assessment. Based on the data in Table 1, 1 kg of CPPL requires 1.3 kg of wet manure, 0.033 kg of sewage sludge, and 0.067 l of water.

The material and energy flows needed to assess the environmental impact of fertilizers were provided by the OpenLCA software, within that the Agribalyse database. The assessment of the environmental impact of fertilizers was based on the production in the factory, so the assessment included the 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 material, etc.

The life cycle inventory analysis of the maize production

For maize production, the inventory includes the field operations (tillage, nutrient replenishment, basic tillage, basic tillage drilling, seedbed preparation, sowing, crop protection, harvesting), the machinery needed for these operations, and all inputs such as seeds, CPPL or NPK fertilizers, pesticides, etc. The process run in the software also considers emissions from fuel combustion. The inventory is limited in time from 'harvest to harvest', but does not take into account post-harvest processes such as drying or storage, even if these operations were also carried out on the farm.

Table 1. Life cycle inventory analysis of Hosoya composting plant

Input material and energy flows	**kg/CPPL**
Broiler manure and litter (with sludge)	1.338 kg
Water	0.067 l
Electricity	0.45 MJ
Natural gas	0.087 MJ
Output anyag- és energiaáramok	
CPPL	1 kg
Emission to air:	
NH_4	0.0012 kg
N_2O	0.00006 kg
CH_4	0.0001 kg

Life cycle impact assessment

The Life cycle impact assessment (LCIA) stage involves processing and evaluating the data collected during the inventory analysis.

In practice, life cycle assessments are carried out using software. The OpenLCA software was chosen for this assessment because it provides a complete set of material and energy flows for all levels of analysis. The software was created in 2006 by a German software development company, Greendelta, with the intention to provide a reliable and powerful software for life cycle assessment. The software is free to download and use. The OpenLCA developers are continuously improving the software, which allows flexible modelling for simple models (Internet4).

The analyses were conducted using the free Agribalyse database, which contains a substantial quantity of data for all of the required analyses (Colomb et al., 2015; Koch and Salou, 2020; Asselin-Balençon et al., 2020).

In this study, the CML IA baseline impact assessment method was used, which is internationally accepted and very widely used. This method was created at Leiden University in the Netherlands in 1992 and its name is derived from the acronym Centrum voor Milieukunde (CML) (Gabathuler, 2006). The most significant impact of the CML methodology is in the area of 'impact assessment'. The CML methodology aims to quantify all direct material and energy exchange relationships between the environment and the product system. The methodology is based on the assumption that emissions with the same effect can be summed across different media, on the other hand, on an impact-oriented classification of material and energy flows. The methodology is in line with international standardisation efforts as it includes goal setting (target and scope), life cycle inventory (inventory analysis), impact analysis (impact assessment) and evaluation (interpretation of results) (Gabathuler, 2006). The CML IA baseline impact assessment method evaluates the processes and products under consideration based on the 11 most commonly used impact categories of life cycle interpretation (Guinée et al., 2002). The three most often utilized impact categories in the literature were used to interpret the current life cycle.

a) Acidification potential (AP). Acidification potential is usually characterized by kg SO_2-equivalence. Acidification potential refers to the compounds that are precursors to acid rain. These include sulphur dioxide (SO_2), nitrogen oxides (NO_x), nitrogen monoxide (NO), nitrogen dioxide (N_2O), and other various substances. These acid gases are usually released into the atmosphere because of fuel combustion. These gases are oxidised in the atmosphere to form sulphuric acid, sulphuric acids and nitric acid, which reduce the pH of precipitation (Guinée et al., 2002).

b) Eutrophication potential (EP). Eutrophication potential is usually characterized by kg PO_4-equivalence. Numerous marine and freshwater ecosystems have been harmed by eutrophication. Excessive growth of algae and plants is caused by increased availability of one or more limiting growth factors (for example, overfertilization or excessive nutrient delivery, with an emphasis on nutrients, especially nitrogen (N) and phosphorus (P)) (Guinée et al., 2002).

c) Global warming potential (GWP). Global warming potential is usually characterized by CO_2-equivalence. Carbon dioxide (CO_2), methane (CH_4), and chlorofluorocarbons (CFCs) are the most frequent greenhouse gases (CFCs). Carbon is present in all of the GHGs. The global warming potential (GWP) is a metric used to compare the effects of various gases on the environment. It is a measure of how much a particular gas, such as 1 tonne, warms the atmosphere over a specific time period (20, 50, or 100 years) as compared to the emission of 1 tonne of carbon dioxide. The higher the GWP, the more negative it is for the environment (Guinée, 2002; IPCC, 2013).

4. Interpretation of LCA results

The interpretation of the life cycle involves interpreting the results and findings from the previous two steps (life cycle inventory analysis (2nd step) and life cycle impact assessment (3rd step)). After the interpretation and evaluation of the results, proposals are formulated. The interpretation phase is also responsible for presenting the inventory analysis results in an intelligible and complete manner in accordance with the study's objectives. The process of interpretation can be used to identify, qualify, and assess conclusions drawn from LCA and LCIA investigations (Muralikrishna and Manickam, 2017; Farjana et al., 2021).

In this study during the interpretation of the LCA results, comparative analyses were carried out to assess the environmental impacts of CPPL. In the first scenario the environmental impact of producing the nutrient supply of a one hundred (100) hectare field was assessed and evaluated. The production of one hundred and fifty tonne (150 t) CPPL was compared to the production of the equivalent macro-element contents of the nitrogen, phosphate and potassium fertilizers combined.

The amount of CPPL to be applied was determined as 1.5 t/ha based on the recommendation of the company producing the product and Szabó et al. (2019). Finally, the amount of each fertilizer to be applied was determined according to the active ingredient content (N-, P_2O_5- and K_2O-content) of CPPL applied at a dose of 1.5 t/ha (Table 2).

Table 2. Quantity of NPK fertilizers to be applied per 100 ha as a function of the active substance content of CPPL

Product	Quantity (t/100 ha)
CPPL (composted and pelletized poultry litter)	150
AN (ammonium nitrate)	24.6/21.5 *
CAN (calcium ammonium nitrate)	30.5/26.7 *
Urea	18/15.7 *
TSP (triple superphosphate)	9.6
MAP (monoammonium phosphate)	8.6
KCl (potassium chloride)	6.25

* Amount of N fertilizers to be applied if the P fertilizer is MAP (considering the N content of MAP)

Since CPPL is a complex active ingredient product containing a combination of both macro and micro elements, the fertilizers were also applied in combination in the scenario. The different fertilizer combinations were as follows, according to the active ingredient content of CPPL (Table 3):

Table 3. Combinations of N, P, K fertilizers and total amount to be applied per 100 hectares

Name of combinations	Composition of NPK combination	t/100 hectare
NPK1	AN + TSP + KCl	40.45
NPK2	AN + MAP + KCl	36.35
NPK3	CAN + TSP + KCl	46.15
NPK4	CAN + MAP + KCl	41.51
NPK5	Urea + TSP + KCl	33.85
NPK6	Urea + MAP + KCl	30.59

According to their environmental impact, the results of the life-cycle evaluation were divided 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.

Results and discussion

Interpretation of LCA results of the production of CPPL (Hosoya composting plant) and fertilizers

The environmental impacts of producing CPPL and various fertilizers were first evaluated per kilogram of end product (Table 4).

Table 4. Results for the production of 1 kg end product

Impact categories	CPPL	AN	CAN	Urea	TSP	MAP	KCl
Acidification potential (kg SO_2-equivalent)	0.024	0.006	0.005	0.005	0.010	0.003	0.002
Eutrophication potential (kg PO_4-equivalent)	0.005	0.002	0.002	0.002	0.004	0.002	0.001
Global warming potential (kg CO_2-equivalent)	0.273	1.382	1.137	1.127	0.657	0.826	0.399

The acidification potential and eutrophication potential, had higher emissions when producing CPPL. The value of acidification potential ranges between 0.002 and 0.01 kg SO_2-equivalent/kg product, regardless of the type of fertilizer. Among the fertilizers, KCl fertilizer had the lowest emission while TSP fertilizer had the greatest emission. Steam generation and extraction and processing of raw materials (SO_2 emission) were the most significant contributing processes for the former, whereas H_2SO_4 production was the most significant contributor for the latter. CPPL (0.024 kg SO_2-equivalent/kg product) produced 93% more emissions than KCl and 58% more emissions than TSP. The high acidification potential value in CPPL is attributed to NH_3 emissions from manure processing. HNO_3 generation (NH_3 and NO emission) for AN and CAN fertilizers, steam production and raw material extraction and processing (SO_2 and NH_3 emission) for urea, and electricity consumption and raw material extraction (SO_2 and NH_3 emission) for MAP fertilizers were the processes that contributed to acidification potential.

A similar trend was observed for emissions in terms of eutrophication potential, the lowest emissions were found for KCl fertilizer (0.0007 kg PO_4-eq/kg KCl) and the highest for TSP (0.0041 kg PO_4-equivalent/kg TSP). The release of phosphate and phosphorus into water during the extraction and processing of raw materials was the source of emissions for both. The eutrophication potential of CPPL was 0.0054 kg PO_4-equivalent, which is 88% higher for the former and 24% higher for the latter fertilizer. In this case, NH_3 and N_2O emissions during the processing of broiler manure and electricity consumption were the contributors to the high environmental load. For the other fertilizers, the contributing processes were similar to those for acidification potential. For AN and CAN fertilizers, HNO_3 production (NH_3 and NO_x emission) and for urea and MAP, extraction and processing of raw materials (PO_4 and NH_3 emission) were the contributing processes of eutrophication potential.

The global warming potential was lowest for CPPL (0.27 kg CO_2-equivalent/kg product). Contributing to emissions were electricity consumption (CO_2 and CH_4 emission), broiler manure processing (N_2O and CH_4 emission), fuel consumption (CO_2 emission) and further treatment of waste generated (CO_2 emission). Among fertilizers, KCl production again had the lowest emissions (0.4 kg CO_2 equivalent/kg KCl). The highest emissions occurred for N fertilizers, and the most important of these was for AN (1.38 kg CO_2-equivalent/kg AN). The production of AN produces five times as many emissions as CPPL. For fertilizers, CO_2 and CH_4 emissions due to the production of steam for fertilizer production are almost uniformly responsible for the high GWP. There is no information on the environmental impacts of producing CPPL using the Hosoya technology; instead, there is literature on similar semi-enclosed and closed composting technologies. Among the different animal manures, Zhu et al. (2014) investigated the composting of chicken manure and litter carcasses. The CO_2 emissions of the system they studied were 3-6 times lower than the Hosoya system. The ADAME (2012) research programme investigated air emissions from composting. The composting of sewage sludge investigated under this study had emissions of 0.089 and 0.298 kg CO_2-equivalent. The latter value is the closest to the 0.27 kg CO_2-equivalent observed for granulated poultry manure. The emissions from composting of livestock waste were also investigated, where the measured values are on average five times higher than the emission value reported in this study. Luske (2010) studied the composting of chicken and beef manure. The emissions of the composting plant he studied were about half (0.147 kg CO_2-equivalent/kg product) of those of the Hosoya composting plant. In general, the authors found that the emissions depend to a large extent on the composition and proportion of the raw materials to be composted and the composting technology.

Overall, because of the gas emissions emitted during manure composting, the acidification and eutrophication potential of CPPL is larger than that of fertilizers, as shown in Table 4. The global warming potential, on the other hand, was lowest during the manufacture of 1 kg CPPL.

The environmental impact of producing a fertilizer supply for a 100 hectare field was studied and evaluated (Table 5) after determining the environmental load per 1 kg of product. A combination of NPK fertilizers was used to compare the output of 150 t of CPPL.

Compared to the NPK fertilizer combinations, the environmental impact of 150 t of CPPL production was higher in terms of the AP (94% on average) and the EP (90% on average). The possible reason for this in the case of AP is the NH_3- and N_2O-emission of organic manure during the composting process, while the high EP is due to NO_3- and PO_4-emissions also during the composting process. Because of the emissions of gases during the composting of organic matter, the production of CPPL may obviously be categorized as having a high environmental impact in terms of acidification and eutrophication potential.

Table 5. Results for the production of CPPL and NPK fertilizers combinations applied for a 100 hectare of arable land

Impact categories	CPPL	NPK1	NPK2	NPK3	NPK4	NPK5	NPK6
Acidification potential (SO_2-equivalent)	3620	262.9	173.3	265.3	175.3	196.0	115.6
Eutrophication potential (kg PO_4-equivalent)	816.1	98.7	65.8	101.0	67.7	75.8	46.1
Global warming potential (kg CO_2-equivalent)	40880	43005	39357	43654	39886	29113	27372

green = low environmental impact; yellow = middle environmental impact; red = high environmental impact

In the case of GWP, comparison to the NPK1 and NPK3 combinations the CPPL produced a smaller global warming potential by 5.5% on average, while the to the NPK2 and NPK4 combinations the CPPL's GWP values were similar. The production of the combinations NPK1 and NPK3 had the highest environmental load, while the production of the combinations NPK2 and NPK4, together with CPPL, belonged to the medium environmental load group. The GWP of those NPK combinations where the N fertilizer was urea (NPK5 and NPK6) was 29–33% lower than CPPL due to low environmental impact of urea production, because urea is the most concentrated nitrogen fertilizer (46% N content) and smaller amounts of it cover the desired quantity. As a result, the production of NPK5 and NPK6 combinations had the lowest environmental burden.

Overall, the results in Table 5, similar to the results in Table 4, indicate that CPPL production has higher acidification and eutrophication potential than NPK fertilizer combinations due to the gases released during manure composting. In terms of global warming potential, the production of 150 t of CPPL falls into the same category of medium environmental impact as the NPK2 and NPK4 combinations. Resulting in a lower environmental burden than NPK1 and NPK3 combinations.

Interpretation of LCA results of the maize production

Continuing with the previous scenario, in the case of maize cultivation's life cycle assessment, 150 t CPPL and the six NPK fertilizer combinations were utilized for nutrient replenishment. So that, in addition to the environmental impact of maize cultivation, the production of CPPL and fertilizers was also taken into account. The environmental impact of maize production was also divided into three categories (low, medium and high environmental burden). The environmental burden was calculated using 1 tonne of harvested crop.

Table 6. Results for maize production (1 tonne) with various nutrient replenishment

Impact categories	CPPL	NPK1	NPK2	NPK3	NPK4	NPK5	NPK6
Acidification potential (kg SO_2-equivalent)	9.06	15.28	15.19	15.28	15.19	15.2	15.11

Eutrophication potential ($kg\ PO_4$-equivalent)	8.79	10.46	10.42	10.47	10.42	10.44	10.39
Global warming potential ($kg\ CO_2$-equivalent)	644.7	928.4	924.5	928.6	926	975.5	972.9

green = low environmental impact; yellow = middle environmental impact; red = high environmental impact

Field operations and fertilizer use are the two main contributions to acidification potential. This explains why, although emissions in the fertilizer scenarios reach 15 kg SO_2-equivalent per 1 tonne of maize, emissions in the CPPL barely exceed 9 kg SO_2-equivalent per 1 tonne of maize. The type of heavy machinery utilized for each field operation, as well as the type of fertilizer used, have a significant impact on emissions. Holka et al. (2017), for example, found 6.6 and 7.9 kg SO_2-equivalent when comparing two systems in Poland.

Field operations and fertilizer use, like acidification potential, are the key contributors to eutrophication potential. Also, for eutrophication potential, the lowest emissions (8.79 kg PO_4-equivalent) were found where nutrient addition was done with CPPL. In this case, emissions were about 16% lower than in maize production scenarios where NPK fertilizers combination were applied.

The global warming potential for maize production with CPPL was 644.7 kg CO_2-equivalent per tonne of maize, while for NPK combinations it was much higher, ranging from 924.5 to 975.5 kg CO_2-equivalent. The two highest values were for NPK5 and NPK6 combinations, probably due to the fact that the N fertilizer in these cases was urea. As with acidification and eutrophication potential, the largest contributors to emissions for this impact category are field operations and fuel use. The majority of the literature is available on GWP.

The literature data are very variable and generally lower than those measured in the present study, which can be explained by the fact that most of the studies investigated non-irrigated conditions, whereas in this study irrigated cropping systems were considered, which includes the operation of the whole irrigation infrastructure from water purchase to irrigation. Wittman et al. (2011) found values of 319.7 and 488 kg CO_2-equivalent/t maize in their research. They concluded that the main contributor to greenhouse gas emissions is the loss of soil organic carbon (40-61%), followed by NO_2 emissions (10-31%) and finally field operations, the most important of which is harvesting (14-22%). Holka et al. (2017) measured 296.8 and 331.1 kg CO_2-equivalent in a comparison of two maize production systems in Poland. In another study, Holka and Bienkowski (2020) compared the CO_2-equivalent emissions of three tillage systems, conventional, reduced and no-tillage. Their results showed no major differences between the systems, with values around 184.8, 189.8 and 178.0 kg CO_2-equivalent/t maize, respectively. Jayasundara et al. (2014) measured 243 and 353 kg CO_2-equivalent, while Supasri et al. (2020) estimated greenhouse gas emissions at 351.2 kg CO_2-equivalent. Among the researchers, Wettstein et al. (2017) compared irrigated and non-irrigated maize cropping systems. Their results show that non-irrigated maize production has emissions of 490 kg CO_2-equivalent per tonne of maize, while irrigated systems have much higher emissions of between 530 and 800 kg CO_2-equivalent.

The results shown could 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. Based on the results of this life cycle assessment, it can be concluded that a substantial reduction in pesticide and fertilizer use is needed to achieve sustainability and reduce environmental pressures. Other solutions include the introduction of reduced tillage systems and the use of single-tillage operations, which would reduce fossil fuel use and greenhouse gas emissions. Emissions could be significantly improved by using more modern machinery and equipment for field operations. Of course, modern technologies and infrastructure are very expensive to install, and in most cases can only be financed through grants.

Conclusion

As a final conclusion, the use of manure-based products should be considered for both environmental and economic reasons.

From an environmental point of view, because it is a valuable nutrient substitute which, when used, does not pollute or contaminate the environment. Although the production of CPPL has a higher acidification and eutrophication potential due to the processing of organic matter, the global warming potential is much more favourable than that of fertilizers. And the environmental impact of crop production is clearly lower with CPPL. The use of fertilizer-based products makes the farm environmentally sustainable and creates a circular economic structure.

From an economic point of view, in the current uncertain fertilizer situation and fertilizer prices (due to high natural gas prices), substitution of fertilizers should be considered to ensure crop security and to meet human and animal nutritional needs, as there is a worldwide shortage of fertilizers, despite the fact that fertilizers were already at record prices last year. This is mainly due to the sharp rise in the price of the main raw material, natural gas, and the resulting decisions to cut production. Several European fertilizer producers, including Yara International ASA and Borealis AG, are cutting production as a result of the rise in natural gas prices. This move further increases the risk of global food shortages. And with Russia's recent announcement to suspend fertilizer exports, the Russia-Ukraine war has completely disrupted commodity markets and pushed up the price of natural gas, a raw material for nitrogen fertilizers, to record levels. This price rise, in turn, is forcing European producers to cut ammonia production, increasing the already high input costs for agricultural businesses and further increasing the risk of global food shock.

Acknowledgement

The research was financed by the Thematic Excellence Programme of the Ministry for Innovation and Technology in Hungary (ED_18-1-2019-0028), within the framework of the Space Sciences thematic programme of the University of Debrecen.

This research was supported by EU grant to Hungary GINOP 2.2.1.-15-2017-00043.

References

Asselin-Balençon, A. – Broekema, R. – Teulon, H. – Gastaldi, G. – Houssier, J. – Moutia, A. – Rousseau, V. – Wermeille, A. – Colomb, V. (2020). AGRIBALYSE v3.0: the French agricultural and food LCI database. Methodology for the food products. Ed. ADEME.

Bhatt, M.J. – Labanya, R. – Joshi, H.C. (2019). Influence of Long-term Chemical fertilizers and Organic Manures on Soil Fertility - A Review. *Universal Journal of Agricultural Research*. 7(5), 177-188. https://doi.org/10.13189/ujar.2019.070502

Bíró, T. – Tamás, J. – Thyll, S. (1998). Risk assessment of nitrate pollution in lower watershed of the Berettyó River. In: Filep, Gy. (ed.) *Soil Water Environment Relationships*, 239–247. Wageningen–Debrecen; Wageningen University and Research, Wageningen, Netherland; University of Debrecen, Debrecen, Hungary.

Chia, S.Y. – Tanga, C.M. – van Loon, J.J. – Dicke, M. (2019): Insects for sustainable animal feed: Inclusive business models involving smallholder farmers. *Current Opinion in Environmental Sustainability. 41*, 23–30. https://doi.org/10.1016/j.cosust.2019.09.003

Colomb, V. – Amar, S.A. – Mens, C.B. – Gac, A. – Gaillard, G. – Koch, P. – Mousset, J. – Salou, T. – Tailleur, A. – van der Werf, H.M.G. (2015). AGRIBALYSE®, the French LCI Database for agricultural products: high quality data for producers and environmental labelling. *Oilseeds and fats, Crops and Lipids. 22(1):*D104. https://doi.org/10.1051/ocl/20140047

Csiba, A. – Fenyvesi, L. (2012). Facilities of poultry manure processing and utilization with environmental technologies. AgEng Konferencia Valencia.

Enahoro, D. – Lannerstad, M. – Pfeifer, C. – Dominguez-Salas, P. Contributions of livestock-derived foods to nutrient supply under changing demand in low- and middle-income countries. *Glob. Food Secur.* **2018**, *19*, 1–10.

Farjana, S.H. – Mahmud, M.A.P. – Huda, N. (2021). *Introduction to Life Cycle Assessment.* In Farjana, S.H. – Mahmud, M.A.P. – Huda, N. (eds.). *Life Cycle Assessment for Sustainable Mining, 1-13.* Elsevier. https://doi.org/10.1016/B978-0-323-85451-1.00001-9

Gaál K. (2011). Trágyakezelés- és hasznosítása a baromfitelepeken. In: Bogenfürst F. – Horn P. – Sütő Z. – Kovácsné Gaál K. – Kovács G. 2011. *Baromfitartás*. Egyetemi jegyzet, Kaposvári Egyetem; Pannon Egyetem; Nyugat-Magyarországi Egyetem.

Gabathuler, H. (2006). The CML Story: How Environmental Sciences Entered the Debate on LCA. *The International Journal of Life Cycle Assessment*. *11*, 127-132. https://doi.org/10.1065/lca2006.04.021

Garcia, A. – Fox, J.G. – Besser T.E. (2010). Zoonotic enterohemorrhagic *Eschericia coli:* A one health perspective. *ILAR Journal. 51(3),* 221–232. https://doi.org/10.1093/ilar.51.3.221

Georgakakis, D. – Krintas, TH. (2000). Optimal use of the Hosoya system composting poultry manure. *Bioresource Technology*. *72(3)*, 227-233. https://doi.org/10.1016/S0960-8524(99)00122-4

Gil-Ortiz, R. – Naranjo, M.Á. – Ruiz-Navarro, A. – Caballero-Molada, M. – Atares, S. – García, C. – Vicente, O. (2020). New Eco-Friendly Polymeric-Coated Urea Fertilizers Enhanced Crop Yield in Wheat. *Agronomy.* 10:438. https://doi.org/10.3390/agronomy10030438

Gil-Ortiz, R. – Naranjo, M.Á. – Ruiz-Navarro, A. – Atares, S. – García, C. – Zotarelli, L. – San Bautista, A. – Vicente, O. (2020). Enhanced Agronomic Efficiency Using a New Controlled-Released, Polymeric-Coated Nitrogen Fertilizer in Rice. *Plants.* 9:1183. https://doi.org/10.3390/plants9091183

Gorliczay, E. – Boczonádi, I. – Kiss, N.É. – Tóth, F.A. – Pabar, S.A. – Bíró, B. – Kovács, L.R. – Tamás, J. (2021). Microbiological Effectivity Evaluation of New Poultry Farming Organic Waste Recycling. *Agriculture*, *11(7)*, 683. https://doi.org/10.3390/agriculture11070683

Guinée, J.B. – Gorree, M. – Heijungs, R. – Huppes, G. – Renekleijn – de Koning, A. – van Oers, L. – Sleeswijk, A.W. – Suh, S. – udo de Haes, H.A. – de Bruijn, H. – van Duin, R. – Huijbregts, M.A.J. – Lindeijer, E. – Roorda, A.A.H. – van der Ven, B.L. – Weidema, B.P. (2002). Handbook on Life Cycle Assessment - Operational Guide to the ISO Standards. Kluwer Academic Publisher, New York, Boston, Dordrecht, London, Moscow.

Han, S.H. – Young, J. – Hwang, J. – Kima, S.B. – Parka, B. (2016). The Effects of Organic Manure and Chemical Fertilizer on the Growth and Nutrient Concentrations of Yellow Poplar (Liriodendron tulipifera Lin.) in a Nursery System*.* *Forest Science and Technology*. *12*, 137–143. https://doi.org/10.1080/21580103.2015.1135827

He, Z. – Pagliari, P.H. – Waldrip, H.M. (2016). Applied and Environmental Chemistry of Animal Manure: A Review. *Pedosphere. 26(6),* 779–816. https://doi.org/10.1016/S1002-0160(15)60087-X

He, Z. (2020): Organic Animal Farming and Comparative Studies of Conventional and Organic Manures. In Waldrip, H.M. – Pagliari, P.H. – He, Z. (eds.) *Animal Manure: Production, Characteristics,* *Environmental Concerns, and Management*. American Society of Agronomy: Madison, WI, USA. *67*, 165–182. https://doi.org/10.2134/asaspecpub67.c9

He, Z. – Pagliari, P.H. – Waldrip, H.M. (2016). Applied and Environmental Chemistry of Animal Manure: A Review. *Pedosphere. 26*, 779–816. https://doi.org/10.1016/S1002-0160(15)60087-X

Heredia, N. – García, S. (2018). Animals as sources of food-borne pathogens: A review. *Animal Nutrition. 4(3),* 250–255. https://doi.org/10.1016/j.aninu.2018.04.006

Holka, M. – Bieńkowski, J.F. – Jankoxiak, J. – Dąbrowicz, R. (2017). Life cycle assessment of grain maize in intensive conventional crop production system. *Romanian Agricultural Research*. 34. https://doi.org/10.20472/IAC.2019.047.006

Holka, M. – Bieńkowski, J.F. (2020). Life cycle assessment of grain maize production in different soil tillage systems. Proceedings of International Academic Conferences 9211579. International Institute of Social and Economic Sciences. https://doi.org/10.20472/IAC.2019.047.006

Janković, L.J. – Petrujkić, B. – Aleksić, N. – Vučinić, M. – Teodorović, R. – Karabasil, N. – Relić, R. – Drašković, V. – Nenadović, K. (2020). Carcass characteristics and meat quality of broilers fed on earthworm (Lumbricus rubellus) meal. *Journal of the Hellenic Veterinary Medical Society. 71(1)*, 2031–2040. https://doi.org/10.12681/jhvms.22953

Jayasundara, S. – Wagner-Riddle, C. – Dias, G. – Kariyapperuma, K.A. (2014). Energy and greenhouse gas intensity of corn (Zea mays L.) production in Ontario: A regional assessment. Canadian *Journal of Soil Science*. 94, 77-95. https://doi.org/10.4141/cjss2013-044

Kasule, L. – Katongole, C. – Nambi-Kasozi, J. – Lumu, R. – Bareeba, F. – Presto, M. – Ivarsson, E. – Lindberg, J.E. (2014). Low nutritive quality of own-mixed chicken rations in Kampala City, Uganda. *Agronomy for Sustainable Development. 34*, 921–926. https://doi.org/10.1007/s13593-013-0205-2

Koch, P. – Salou, T. (2020). AGRIBALYSE®: Methodology, Agricultural stage – Version 3.0. Ed ADAME, Angers, France.

Luske, B. (2010). Reduced GHG Emissions due to Compost Production and Compost Use in Egypt. Comparing Two Scenarios; 2010-016 LbD; Louis Bolk Instituut, Bunnik, The Netherlands.

Magnusson, U. *Sustainable Global Livestock Development for Food Security and Nutrition Including Roles for Sweden*; Ministry of Enterprise and Innovation: Stockholm, Sweden; Swedish FAO Committee: Stockholm, Sweden, 2016.

Messiga, A.J. – Dyck, K. – Ronda, K. – Van Baar, K. – Haak, D. – Yu, S. – Dorais, M. (2020). Nutrients Leaching in Response to Long-Term Fertigation and Broadcast Nitrogen in Blueberry Production. *Plants.* 9:1530. https://doi.org/10.3390/plants9111530

Mézes, L. – Nagy, A. – Gálya, B. – Tamás, J. (2015). Poultry feather wastes recycling possibility as soil nutrient*. Eurasian Journal of Soil Science*. 4, 244–252. http://dx.doi.org/10.18393/ejss.2015.4.244-252

Modderman, C. (2020). Composting with or without additives. In Waldrip, H.M. – Pagliari, P.H. – He, Z. (eds.) Animal Manure: Production, Characteristics, Environmental Concerns, and Management – American Society of Agronomy: Madison, WI, USA. *67,* 245–254.

Moyo, S. – Swanepoel, F.J.C. (2010). Multifunctionality of livestock in developing communities. In Swanepoel, F.J.C. – Stroebel, A. – Moyo, S. (eds.) *The Role of Livestock in Developing Communities: Enhancing Multifunctionality*. University of Free State (UFS) and the technical Centre for Agricultural and Rural Cooperation (CTA). Cape Town, South Africa; Wageningen, The Netherlands. 1–11.

Muralikrishna, I.V. – Manickam, V. (2017). Life Cycle Assessment. In Muralikrishna, I.V. – Manickam, V. (eds.). *Environmental Management. Science and Engineering for Industry*, 57-75. Butterworth-Heinemann. https://doi.org/10.1016/B978-0-12-811989-1.00005-1

Nalunga, A. – Komakech, A.J. – Jjagwe, J. – Magala, H. – Lederer, J. (2021). Growth characteristics and meat quality of broiler chickens fed earthworm meal from Eudrilus eugeniae as a protein source. *Livestock Science. 245*, 104394. https://doi.org/10.1016/j.livsci.2021.104394

Savci, S. (2012). Investigation of effect of chemical fertilizers on environment. *APCBEE Procedia.* 1, 287-292. https://doi.org/10.1016/j.apcbee.2012.03.047

Stefanovits P. – Filep GY. – Füleky Gy. (1999). Talajtan. Mezőgazda Kiadó, Budapest.

Supasri, T. – Itsubo, N. – Gheewala, S.H. – Sampattagul, S. (2020). Life cycle assessment of maize cultivation and biomass utilization in northern Thailand. *Scientific Reports*. *10,* 3516.

Szabó L. (2016). Hosoya trágyakezelési technológia. Gödöllő

Szabó, A. – Tamás, J. – Nagy, A. (2019). Spectral evaluation of the effect of poultry manure pellets on pigment content of maize (*Zea mays* L.) and wheat (*Triticum aestivum* L.) seedlings. *Natural Resources and Sustainable Development. 9(1)*, 70–79. https://doi.org/10.31924/nrsd.v9i1.025

Van Harn, J. – Dijkslag, M.A. – Van Krimpen, M.M. (2019). Effect of low protein diets supplemented with free amino acids on growth performance, slaughter yield, litter quality, and footpad lesions of male broilers*. Poultry Science*. *98,* 4868–4877.

Versino, F. – Urriza, M. – García, M.A. (2019). Eco-compatible cassava starch films for fertilizer controlled-release. *International Journal of Biological Macromolecules*. 134, 302-307. https://doi.org/10.1016/j.ijbiomac.2019.05.037

Wettstein, S. – Muir, K. – Scharfy, D. – Stucki, M. (2017). The environmental mitigation potential of photovoltaic-powered irrigation in the production of south african maize. *Sustainability*. *9(10),* 1772. https://doi.org/10.3390/su9101772

Xiaoyu, N. – Yuejin, W. – Zehngyan, W. – Lin, W. – Guannan, Q. – Lixiang, Y. (2013). A novel slow-release urea fertiliser: Physical and chemical analysis of its structure and study of its release mechanism. *Biosystems Engineering.* 115, 274-282. https://doi.org/10.1016/j.biosystemseng.2013.04.001

Zhu, Z. – Dong, H. – Xi, J. – Xin, H. (2014). Ammonia and greenhouse gas emissions from co-composting of dead hens with manure as affected by forced aeration rate. Trans. ASABE American Society of Agricultural and Biological Engineering. *57(1),* 211–217. https://doi.org/10.13031/trans.57.10206

Internet1:
https://eur-lex.europa.eu/resource.html?uri=cellar:b828d165-1c22-11ea-8c1f-01aa75ed71a1.0012.02/DOC_1&format=PDF

Internet2:

HOSOYA & CO. (1996). Hosoya Manure Fermentation System. Hoyosa & Co., 412 Fukaya, Ayase-Shi, Kanagawa-ken 252, Japan.

http://www.k-hosoya.co.jp/en/product/

Internet3:

http://www.k-hosoya.co.jp/en/file/pdf/Hosoy%20Poultry%20Manure%20Fermentation%20System%20ver200602.pdf

Internet4: www.openlca.org