Environmental impact assessment of maize cultivation system considering different irrigation methods

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Abstract

Maize is a key crop for the livestock sector being able to produce different fodder. Among these, ear maize silage is widely used as an energy source in the diets of pigs, dairy cows and fattening cattle. Given the variability of rainfall, irrigation plays a relevant role to achieve both satisfactory productivity and product quality. In this context, it is essential to explore the sustainability of different irrigation methods for maize cultivation.In this study, Life Cycle Assessment (LCA) was applied to evaluate the environmental impact of maize farms using different irrigation systems: pivot, drip, flood, and hose irrigation. One ton of ear maize silage at 48% moisture content was selected as functional unit and a "from cradle to farm gate" was considered as system boundary . Primary inventory data were collected mainly by surveys and interviews with the farmers. The Environmental Footprint 3.1 method was used to assess 14 impact categories. The results do not allow to clearly identify the best irrigation method across all environmental impact categories, therefore highlighting the need of trade-offs. While yield is the primary driver of environmental impacts, the influence of irrigation remains significant. Climate change was found to range from 116.66 kg CO_2 eq./t of ear maize for flood irrigation to 207.42 kg CO_2 eq./t for hose irrigation. Water use varied from 2178.29 m^3 depriv./t for pivot irrigation to 10380.65 m^3 depriv./t for flood irrigation. Regarding the contribution analysis, changing the considered environmental impact the main contribution varies, for example nitrous oxide is the main responsible to climate change, ammonia to particulate matter and acidification while nitrate and ammonia emissions to marine eutrophication. In conclusion, this study provides a basis for evaluating different irrigation methods, emphasising that irrigation plays a significant role in the overall environmental impact of maize cultivation, regardless of the end product.

Keywords

Environmental sustainability, Life Cyle Assessment, Irrigation, Maize ear.

Introduction

Maize (*Zea mays L.*) is one of the most widespread and important crops in the world and is a key crop in global agriculture for animal and human nutrition and energy production. Its versatility and adaptability to different climates make it an irreplaceable agricultural resource, with a steady growth in production in the recent decades.

The maize production dynamics over the last 20-30 years build on earlier trends. Since 1961, the global area under maize production nearly doubled, up from 106 million ha to the current 197 million ha (+ 87%), with a stronger acceleration from the early 2000s. On current trends, and with the area dedicated to wheat cultivation that is relatively stagnant, maize is set to overtake wheat as the most widely grown crop worldwide by 2030 (*Erenstein et al., 2021*). The global maize grain yields nearly tripled since 1961, up from 2 tons/ha to the current 5.8 tons/ha (+ 190%). This concentration of supply has direct implications for international prices and the stability of the global maize market. Maize cultivation spans both emerging economies and the developed world including 165 countries distributed across the Americas, Asia, Europe and Africa. The global maize area is primarily located in the Americas (33%) and Asia (33%), followed by Africa (20%) and Europe (10%)(*Erenstein et al., 2022*).

In Italy, maize is mainly grown in the northern regions, where is produced more than 90% of the national production; here, soil texture and pH, water availability and climatic conditions are particularly suitable to produce high-quality maize. Given this intensive production and crop availability, the presence of livestock farms is favored, especially of dairy cattle and beef cattle (43%) and pigs, which account for about 57% of the national livestock production (*ISTAT, 2024*). Despite the challenges posed by climate change and market fluctuations, Italy has maintained a significant role in European maize production, partially due to innovations and the adoption of sustainable agricultural practices (*CREA, 2024*).

Maize grain production in Italy is about 11 million tons, obtained from about 1.1 million hectares under cultivation, (10 t/ha average yield, much higher than the world average yield of 5.8 t/ha) out of a total of about 13 million hectares of utilised agricultural area (UAA) nationwide (*Blandino and Reyneri, 2018*).

The studied area (Po Valley) is one of the areas where maize productivity is the highest and it is representative of temperate areas characterised by good soil fertility, water availability and, consequently of an agro-food system based on the availability of a valuable forage material such as maize silage with a low production cost. Currently, the conversion to non-irrigated maize cultivation is neither economically nor culturally sustainable. Irrigation is an integral part of the region's agricultural system, shaped over the centuries and based on water-demanding crops, such as maize, which is one of the mainstays of livestock diets.

Technically and economically, maize is irreplaceable within the local production system, as it provides the largest amount of fodder for cattle and pig rations. Its replacement by crops with lower water requirements would imply a reduction in productivity, with repercussions on the entire livestock chain.

Consequently, water resource management cannot ignore solutions to preserve the current production model, considering that nowadays it is still possible to produce maize with the current production model, although with more attention on the irrigation technique and water resource use, the first solutions that can be investigated to maintain satisfactory maize productivity and its related overall sustainability in this production area include the evaluation of different irrigation techniques.

In particular, the provinces of Cremona, Padua, Brescia and Mantua alone account for 26% of national production. Compared to 2022, which was a very difficult year for maize cultivation due to a major drought, in 2023 the area dedicated to maize cultivation decreased by 10%, but production yields were significantly higher, from 8.4 to 10.3 tons per hectare. This allowed production to exceed 5.2 million tons, up 10.6% from 4.7 million in 2022 (*Lavorano, 2023*).

Indeed, water availability for irrigation is a key aspect for the achievement of satisfactory yield as well as for producing maize products (grain and silages) of suitable quality for animal feeding. This is becoming a limiting factor in the most recent years due to the challenges posed by climate change, with drought events during summer and rainfall events more intense but less frequent (Žalud *et al*., 2017).

In this context, research and innovation continue to be crucial to maintain the competitiveness and sustainability of maize cultivation in Italy. The demand for maize for animal feed purposes must be balanced with the need for sustainable production that minimises environmental impact and ensures long-term food security. Given the multiple uses of maize, the production in northern Italy has three main pathways:

- The green silage maize: it contains most of the plant, including the stem, leaves and spike. It is used as feed for dairy and meat cattle. Its composition makes it a highly energetic source for animals. The leaves and stem help to provide a fraction of dietary fiber that serves for the digestion process. The ear, however, is rich in starch, a source of energy. In recent years, in addition to animal feed, green silage maize is also used in other production cycles aimed to produce energy or biofuels, such as anaerobic digestion or biodiesel.
- The maize grain: it is the product obtained from the dried grains, removed from the respective bracts and cob. The dry mass of the maize grain consists mainly of starch, a significant source of energy in animals diets. It is used in human nutrition, to produce a wide range of food products, including corn flour, polenta, snacks and

popcorn, for animal feed and in the milling industry to produce flours (Singh *et al*., 2014).

- The ear maize, the focus of this study, is the product obtained by grinding the corn maize complete with bracts and cob. It is ensiled in special storage trenches.

Ear maize is rich in starch, protein, fat, fiber, vitamins and minerals, making it useful as an energy source in the diet of pigs, chickens, dairy cows and fattening cattle.
In any case, given the importance of ear maize as an ingredient in the feed ration of cattle and pigs, the assessment of its sustainability is a very important aspect to evaluate with a view to optimising the entire supply chain, from mechanical operations in the field, irrigation, harvesting and finally ensiling (Li *et al*., 2022).

To assess the environmental performance of products (processes or services), the Life Cycle Assessment (LCA) approach is the most widely used methodology. It is a standardised approach for quantifying different categories of impact (effects on the environment). Although originally developed for industrial systems, LCA is becoming increasingly important in the agri-food sector (Grant and Beer, *2008;* Zucaro *et al., 2014*).

Previous studies on the LCA of maize cultivation have found that the key operations for maize cultivation are seedbed preparation, fertilisation, irrigation, harvesting, and trench ensiling. In Canaj *et al. (2022)* the water-energy-environment interactions of maize production in Albania were analysed. Regarding the Italian context, Noya *et al. (2015)* compared different cultivation practices characterised by different pre-sowing fertiliser applications, Bacenetti *et al. (2016)* compared different methods to spread organic fertilisers (e.g. surface versus direct injection method) and Fantin *et al. (2017)* focused the attention on maize production in Italian cooperatives. However, none of these LCA studies have addressed the different irrigation systems from an environmental point of view, despite irrigation plays a key role in defining the crop's productive performance and, consequently, its economic and environmental outcomes.

In this context, this study aims at evaluating the environmental performances of maize ear production considering different irrigation methods in the cultivation practice: flood irrigation, drip irrigation, hose irrigation and pivot.

To this purpose field trials were carried out during the growing season 2023 in different farms in northern Italy. Besides the quantification of the environmental load considering a full list of environmental indicators, a contribution analysis was also carried out to identify the sub-processes mainly responsible of the environmental impact of maize cultivation.

Materials and Methods

Goal and scope definition

The goal of this study was to evaluate from an environmental point of view the different irrigation systems available in Lombardy for the cultivation of maize, using tools from innovative agriculture and agriculture 4.0.

To achieve the environmental goal, the Life Cycle Assessment (LCA) approach was applied to assess the potential environmental impacts of different irrigation methods on maize cultivation, following the ISO 14040/44 standards (*ISO 14040, 2006 and ISO 14044, 2006*) and the Product Category Rules for arable crops (EPD international*, 2020:07*). In detail, this LCA study aims to:

- Evaluate the environmental impact of ear maize silage;
- Identify how the adoption of different irrigation methods can affect the impact of maize cultivation practice;
- Quantify the possible environmental benefits associated with the adoption of irrigation systems with higher efficiency.

The target audience for this study are policymakers involved in the definition of subsidy framework both at local and international level, stakeholders involved in the feed, dairy and meat supply chain, where maize ear is one of the main used components used in cattle and pig feed.

Functional unit

The Functional unit (FU) is defined as a quantified performance of a product system to be used as a reference unit in an LCA (ISO 14044, 2006). The main function of the maize cultivation practice is the production of ear maize silage for feed purposes. Since maize stalks were not harvested, ear maize represents the only product of the evaluated systems. Consequently, the function provided was quantified in terms of mass of ear maize silage and the selected functional unit was 1 ton of ear maize with 48% of moisture, as also reported in the *PCRs arable and vegetable crop* (EPD international*, 2020:07*).

System boundary

Concerning the system boundary, a "from cradle to farm gate" approach was applied. Consequently, the system boundary included all the activities carried out from the extraction of the raw materials to the ensiling of ear maize (Figure 1). In detail, the following aspects were considered: i) extraction of raw materials (e.g. fossil fuels, metals and minerals); ii) manufacture, maintenance and disposal of the capital goods (e.g. tractors, agricultural machines, shed and grain dryer); iii) production of the different inputs (fertilisers, pesticides, electricity, diesel, etc.); iv) emissions related to the use of input factors (e.g., emissions due to the application of fertilisers, emissions due to the diesel fuel combustion in the tractor engine). The emission sources considered referred to: N and P compounds mainly related with fertilisation, emissions of pollutants due to the combustion of fuels in the engines and emissions related to the distribution of pesticides.

According to the Product Category Rules for "Arable and vegetable crops" (EPD international, *2020:07*) and considering that the fields were dedicated to maize cultivation by more than 20 years, no changes in the soil organic carbon content were considered. On the other hand, there was no evidence that the adoption of different irrigation systems could affect significantly the soil organic matter.

As stalks were left into the field and were incorporated during primary soil tillage operations, no allocation was carried.

Description of maize production system

The selected farms are located in the Po Valley, which is the main maize cultivation area in Italy. Po Valley is characterised by pedoclimatic conditions particularly favourable for maize cultivation (i.e., fertile soils, water availability) and it is one of the main maize production areas at the European level. Therefore, the cultivation practice of the selected farms is representative for maize cultivation in these conditions, and the achieved results could be upscaled to other maize cultivation areas with a similar pedoclimatic context.

The 4 analysed farms are (Table 1):

1- Farm 1; 45°15'N 9°53'E with pivot irrigation system;
2- Farm 2; 49°27'N 10°24'E with flood irrigation system;
3- Farm 3; 49°27'N 10°24'E with drip irrigation system;
4- Farm 4; 45°13'N 10°25'E with hose irrigation system.

In general, the maize cultivation practice included a series of field operations that can be divided into 3 main sections:

Section 1: soil tillage and sowing. Ploughing is one of the main processing of the maize cultivation. It was performed with a mouldboard plough (30 cm depth), in order to incorporate into the soil the stalks from the previous growing season. Then, the field was prepared for sowing by harrowing (with a rotary harrow). Usually, organic or mineral fertilisation is carried out before sowing. The sowing was performed using a precision seeder.

Section 2: crop management. In this section two main operations were included: the chemical control of weeds and diseases and fertilisation.

Section 3: harvesting and ensiling. The harvesting operations were carried out by combine harvesters when the moisture content of ear maize was of about 48% (depending on climatic conditions). Ear maize was loaded into farm trailers coupled with tractors, and then it was transported to the farm where it was ensiled. The maize stalks were left on the ground.

Inventory data collection

Primary data was collected through interviews with the farmers and surveys in the maize fields during the cultivation period. Secondary data were obtained from database for LCA studies (e.g., Ecoinvent® 3.9), scientific literature or were estimated using specific models. An example of an inventory table for farm 1 can be seen in Table 2. For the other farms it is reported in Tables S2-S4.

The information about the cultivation practice (sequence of field operations, timing, working time, characteristics of tractors and operative machines used, and agricultural inputs (e.g., seeds, fertilisers, plant protection products, fuels, etc.) was obtained directly from the farmers during the interviews (Tables S1-S4).

The impact related to the mechanisation of field operations was modelled considering diesel consumption, mass of different machines and considering their annual use, working time as well as their useful life. The diesel fuel consumption was estimated considering the power requirements by the machines, their effective field capacity, and the soil characteristics according to Lovarelli and Bacenetti *(2017)*.

In regard of irrigation efficiency, which is a key parameter for assessing water supply effectiveness, it was defined as the ratio of water stored in the root zone to the water applied to the field (Israelsen and Hansen, 1962). The studied irrigation methods exhibit varying efficiencies: pivot 85%, drip 95%, flood 55%, and hose irrigation 75% (Blandino *et al*., 2018).

Emissions of nitrogen (nitrate, ammonia, nitrogen monoxide, nitrous oxide) and phosphorus (phosphate) compounds were modelled according to Brentrup *et al., (2000)*. Consequently, these emissions were estimated based on: (i) the average temperature at the organic fertiliser spreading; (ii) the time between spreading and incorporation of the fertilisers; (iii) the infiltration rate; (iv) the soil characteristics (texture, pH, etc.); (v) summer and autumn rainfall and (v) the nitrogen and phosphorus content of applied organic and mineral fertilisers; (vi) the nitrogen supply due to atmospheric deposition; (vii) the nutrient content of the maize ear.

Emissions due to the use and application of pesticides were estimated according to *Rosenbaum et al., 2015*, which identified the following dispersion rates of active ingredients: 90% in soil, 9% in air and 1% in water, as also reported in PCR for arable and vegetable crop, (EPD international*, 2020:07*).

Background data regarding the production of the different production factors used (fertilisers, seeds, pesticides, fuels, energy, agricultural equipment, dryer) were retrieved from the Ecoinvent database v3.9 (Weidema *et al., 2013;* Moreno Ruiz *et al., 2016*).

The list of processes retrieved from the databases is reported in the Table S10.

Life cycle impact assessment (LCIA)

The characterisation of inventory data to potential environmental impacts was carried out using the characterised factors provided by the Environmental Footprint 3.1 (adapted) V1.00 / EF 3.1 normalization and weighting set method (Bassi *et al*., 2023). The following impact categories were analysed:

- Acidification (A, expressed as mol H+ eq.);
- Climate change (CC, expressed as mass of CO_2 eq.);

- Ecotoxicity, freshwater (FEx expressed as CTUe);
- Particulate matter (PM expressed as disease inc.);
- Eutrophication, marine (ME expressed as mass of N eq.);
- Eutrophication, freshwater (FE expressed as mass of P eq.);
- Eutrophication, terrestrial (TE expressed as mol N eq.);
- Ozone depletion (OD, expressed as mass of CFC-11 eq.);
- Human toxicity, non-cancer (HT - noc, expressed as CTUh);
- Human toxicity, cancer (HT - c, expressed as CTUh);
- Photochemical ozone formation (POF, expressed as mass of NMVOC eq.);
- Resource use, fossils (FRU, expressed as MJ);
- Resource use, minerals and metals (MMRU, expressed as mass of Sb eq.);
- Water use (WU, expressed as m^3 depriv.).

In total, 14 midpoint impact categories were evaluated. Land use was excluded due to the lack of details on the modelling of this impact categories regarding some production factors consumed during maize cultivation, while ionizing radiation was excluded on account of the low prevalence of nuclear power in the region.

Results

This section is divided in three subsections, in the first one the absolute and relative results are presented while the second part focuses on the contribution analysis.

Absolute environmental results

Table 3 reports the absolute results for the selected functional unit (1 ton of ear maize) in the different farms characterised by the 4 different irrigation methods while the relative comparison is shown in Figure 2.

The comparison among the different cultivation practices with different irrigation methods does not provide a clear indication regarding the least impacting one; depending on the selected impact category the best solution varies. In detail, (i) Farm 1 (irrigation with pivot) shows the best results for 4 out of 14 impact categories (ME, OD, POF and WU), while it is the worst for AC, PM and TE; (ii) Farm 2 (flood irrigation) shows the lowest impact in 4 out of 14 impact categories (CC, HT-c, HT-nc and RUMM), but at the same time, it is the worst in the water use category (WU), because the flood irrigation technique requires a large amount of water; (iii) Farm 3 (drip irrigation) is the least impacting one in 6 out of 14 impact categories (AC, FEx, PM, FE, TE and RUF), and it is never the worst solution and, (iv) Farm 4 (hose irrigation) presents the highest impact for 10 of the 14 evaluated impact categories and for none is the least impacting solution.

<u>Acidification</u>: for farm 1(irrigation with pivot) the average impact is 6.95 mol H+ eq with a variation from 2.13 to 12.83 mol H+ eq/t of ear maize silage, with Farm 3 (drip) being the best and Farm 1 (pivot) the worst, the standard deviation being 4.72 mol H+ eq/t of ear maize silage.

<u>Climate change</u>: this impact ranges from 116.66 to 207.42 kg CO_2 eq/t of ear maize silage with farm 2 (flood) being the best and farm 4 (hose) the worst (*Figure 3b*). In general, pivot and flood irrigation (Farm 1 and 2) have a much lower CC (118.38 – 116.66 kg CO_2 eq/t of ear maize silage) than the rest of the farms using drip and hose irrigation (125.36 – 207.42 kg CO_2 eq/t of ear maize silage). The average impact is 141.96 kg CO_2 eq and the standard deviation is 43.80 kg CO_2 eq for the selected functional unit. For farms 1 and 4 (pivot and hose, respectively), the impact is mainly due to nitrous oxide emissions associated with slurry and manure distribution (60 - 98 kg CO_2 eq/t of ear maize silage).

<u>Ecotoxicity freshwater</u>: in this impact category, Farms 1 and 4 (pivot and hose) have extremely high impacts due to the emissions of plant protection products used for pest control (23758 CTUe and 24138 CTUe for the selected functional unit). The average impact is 14180.39 CTUe/t of ear maize silage and the standard deviation is 12769.03 CTUe/t of ear maize silage.

<u>Particulate matter</u>: for PM the average impact is 33.14 disease inc./10^6/t of ear maize silage with a variation from 13.63 to 88.79 disease inc./10^6/t of ear maize silage, with Farm 3 (drip irrigation) being the best and Farm 1 (irrigation with pivot) the worst; the standard deviation is 47.22 disease inc./10^6 for the selected functional unit.

<u>Eutrophication, marine</u>: for ME, Farm 4 (hose irrigation) shows a higher impact caused by the use of urea during top fertilisation. The average impact is 6.10 kg N eq/t of ear maize silage with a variation from 3.29 to 10.20 kg N eq for the selected functional unit. The standard deviation is 3.02 kg N eq/t of ear maize silage.

<u>Eutrophication, freshwater</u>: this impact ranges from 0.04 to 0.13 kg P eq/t of ear maize silage with Farm 3 (drip irrigation) being the best and Farm 4 (hose irrigation) the worst (Figure 3f). In general, flood and drip irrigation (Farms 2 and 3) have a much lower FE (0.09 - 0.04 kg P eq/t of ear maize silage) than the rest of the farms using pivot and hose irrigation (0.12 – 0.13 kg P eq/t of ear maize silage). The average impact is 0.09 kg P eq/t of ear maize silage and the standard deviation is 0.04 kg P eq for the selected functional unit.

<u>Eutrophication, terrestrial</u>: as already seen for A and PM, also in the TE impact category the greatest impact is caused by ammonia emissions. The best performing farms are 3 and 2 with drip and flood irrigation (9.42 – 19.37 mol N eq/t of ear maize silage) while the two worst performing farms are 1 and 4 with pivot and hose irrigation (57.04 – 37.57 mol N eq/t of ear maize silage). The average impact is 20.99 mol N eq and the standard deviation is 30.85 mol N eq for the selected functional unit.

Human toxicity – cancer: this impact ranges from 0.14 to 0.37 CTUh/10^7/t of ear maize silage with Farms 2 and 3 (flood and drip, respectively) being the best and Farm 4 (hose irrigation) the worst. In general, flood and drip irrigation (2 and 3) show a lower HT-c (0.14 - 0.14 CTUh/10^7/t of ear maize silage) than the other two cultivation practice using pivot and hose irrigation (0.20 - 0.37 CTUh/10^7/t of ear maize silage) because they don't use mineral fertiliser (urea) which is part of the production factor category. The average impact is 0.21 CTUh/10^7 and the standard deviation is 0.11 CTUh/10^7 for the selected functional unit.

Human toxicity – non cancer: this impact ranges from 1.93 to 5.93 CTUh/10^7/t of ear maize silage, with Farm 2 being the best and Farm 4 the worst (flood and hose, respectively). The average impact is 3.70 CTUh/10^7/t of ear maize silage and the standard deviation is 1.65 CTUh/10^7/t of ear maize silage.

Ozone depletion: for OD the average impact is 4.32 mg CFC11 eq/t of ear maize silage with a variation from 2.93 to 5.96 mg CFC11 eq/t of ear maize silage, with Farm 1 (pivot) being the best and Farm 4 (hose irrigation) the worst; the standard deviation is 1.25 mg CFC11 eq/t of ear maize silage.

Photochemical ozone formation: for this impact category, the results are like to the OD previously described. Differences can be seen in a higher impact of irrigation; in fact, it is important to see how Farm 4 with the hose irrigation method impacts about 30% of the total. This impact is mainly due to the major diesel use of this irrigation method, compared with other methods that consume less fuel or run on electricity.
The average impact is 0.46 kg NMVOC eq/t of ear maize silage and the standard deviation is 0.16 kg NMVOC eq/t of ear maize silage.

Resource use, fossils: the impact ranges from 561.41 to 1439.94 MJ for the selected functional unit, with Farm 3 (drip irrigation) being the best and Farm 4 (hose irrigation) the worst (Figure 3l). The average impact is 854.20 MJ/t of ear maize silage and the standard deviation is 399.95 MJ/t of ear maize silage.

Resource use, minerals and metals: in this category the most important difference with the FRU described above is given by irrigation, in fact, the Farm 3, with drip irrigation, has a very important impact that exceeds 66% of the total. This is due to the use of metals for the construction of the pumping, filtration and adduction plant. The average impact is 0.32 g Sb eq/t of ear maize silage and the standard deviation is 0.11 g Sb eq/t of ear maize silage.

Water use: this impact varies from 2178 to 10380 m^3 depriv. for the selected functional unit, with Farm 1 (pivot) as best and Farm 2 (flood) as worst (Figure 3n). The average impact is 4259 m^3 depriv./t of ear maize silage and the standard deviation is 4081 m^3 depriv./t of ear maize silage. For this impact categories, the irrigation system is the main driver of the environmental results: the flood irrigation method turns out to be the worst in terms of amount of water (9869 m^3 depriv./t of ear maize silage) while the drip irrigation is the best (1659 m^3 depriv./t of ear maize silage).

Contribution analysis

Figure 3 shows the results of the contribution analysis; for each impact category, the share of impact related to the different inputs and outputs is identified. In the figure, the inputs and outputs were grouped as follow:

- Mechanisation, including all the field operations except for the irrigation. For each field operation, the fuel consumption and the related exhaust gases emissions were considered, as well as the impact due to manufacturing, maintenance and disposal of the machinery.
- Irrigation, including the same input and output previously described for a generic field operation.
- Production factors summing up the impact related to the production and distribution at the farm (e.g. seeds, fertilisers, pesticides).
- Water use was considered to be a negligible contribution for all the evaluated impact categories except for the water use where, as expected, is the main responsible of the total impact.
- The impact contributions due to the emission of different N and P compounds were not grouped to better highlight their role on the different environmental effects.

In detail, the share of the total impact related to irrigation varies greatly for the different impact categories considered and ranges from 3.46% for CC in Farm 3 with drip irrigation to 14.59% of CC in Farm 4 (hose irrigation). The environmental impact of maize cultivation for A, CC, PM, FE, ME and TE categories is mainly due to nitrogen (N) and phosphorus (P) emissions. These result from nitrate leaching, nitrous oxide emissions, phosphate and ammonia volatilisation.

The remaining mechanical operations, such as plowing, harrowing, seeding, mineral fertiliser and pesticide distribution, are responsible for most of the impact on the following categories: OD from 56% to 95%, POF from 55% to 95%, HT-nc from 19% to 52%, HT-c from 32% to 78%, and part of CC, with values ranging from 20% to 33%. An analysis of the contributions for each impact category considered is shown below:

Acidification (A): Ammonia emission is responsible for most of the impact (>95%) in all cultivation practices (Figure 3a). This emission is mainly due to volatilisation during the spreading of organic fertilisers (slurry and digestate), the two worst cases are specifically farm 1 which spreads 80 t/ha of cattle manure (N 0.4%) and farm 4 which spreads 75 t/ha of cattle slurry while the emission due to the application of mineral fertilisers plays a less significant role (<5%). For Farms 2 and 3 (flood and drip), emissions of ammonia from slurry distribution are reduced due to the use of a slurry spreader equipped with an injection system.

Climate change (CC): the largest contributor to this impact category is nitrous oxide, which accounts for 47% to 67% of the impact in the four farms. However, the key difference between the analysed companies is the impact of production factors. In farms 1 and 4 (pivot and hose irrigation), these factors contribute 22.67 kg CO_2 eq. and 35.35 kg CO_2 eq. respectively (accounting for 19% and 17% of the total impact), whereas in farms 2 and 3, their contribution is less than 2%. This discrepancy is primarily due to the use of urea in farms 1 and 4, which is not used by farms 2 and 3. The impact of irrigation is not negligible, in farm 1 with pivot irrigation it is 11%, in farm 2 with flood irrigation it is 8%, farm 3 which has drip irrigation has an impact of 3.5% and finally farm 4, found to have the worst method in CC, with hose irrigation has 15%.

Ecotoxicity, freshwater (FEx): the major impact in this category is due to production factors, specifically caused by two plant protection products used on farms 1 and 4 (pivot and hose irrigation) that contain deltamethrin, an active ingredient that significantly influences (97% for both farms) this impact category. Farms 2 and 3 (flood and drip irrigation) use other plant protection products that do not have this type of emission because they are herbicides and do not contain deltamethrin as an active ingredient.

Particulate matter (PM): ammonia emission is responsible for most of the impact, more than 97%. Again, as with acidification, emissions are mainly due to volatilisation during the spreading of fertilisers.

Eutrophication, marine (ME): in the marine eutrophication impact category, the share of impact related to nitrate is predominant in the four considered farms, 85% F1, 94% F2, 97% F3, and 95% for farm 4 respectively. The remaining impact is divided between ammonia (<11%) and mechanisation (<4%).

Eutrophication, freshwater (FE): impact is mainly due to phosphate emissions associated with slurry and manure distribution. The largest contributor to this impact category is phosphate, which accounts for 75% to 100% of the impact in the four farms.

Eutrophication, terrestrial (TE): ammonia emission is responsible for most of the impact, ranging from 86% to 98%, on all farms. Again, as with acidification and particulate matter, emissions are mainly due to volatilisation during fertiliser spreading.

Human toxicity – cancer (HT – c): the four farms have similar impacts for mechanisation, where plowing, harrowing, and harvesting operations have an important influence on the result with percentages ranging from 32% (farm 4) to 79% (farm 2). Irrigation has an important weight in this impact category, e.g., hose irrigation in farm 4 has an impact of about 38% of the total, 42% for drip irrigation in farm 3, and 40% for pivot irrigation in farm 1. Flood irrigation, at the same time, is the best irrigation method in the HT - c impact category with an impact of just over 20%. Also, in this category it is important to emphasise the impact of production factors, in this case urea production purchased and used on farms 1 and 4 impacts 35% (farm 1) and 27% (farm 4).

Human toxicity – non cancer (HT - nc): as with HT-c, the four farms have similar impacts on mechanisation, these range from 19% on farm 1 to 51% on farm 2. Within the mechanisation of farm 2, the most impactful operations are plowing with a contribution of 14%, harrowing with 7%, and finally harvesting with 7%. For HT - nc, irrigation also has a major weight in this impact category, for example, drip irrigation on farm 3 has an impact of more than 70% of the total, with most of this impact coming from the use of large amounts of plastic for irrigation pipes. Flood irrigation, at the same time, is the best in the HT - nc impact category. The impact of production factors is not negligible in farms 1 and 4 due to the use of urea previously seen.

Ozone depletion (OD): mechanisation is responsible for most of the impact on all farms, due to emissions associated with diesel combustion in the machinery engine. The contribution is 56% on farm 1, 91% on farm 2, 95% on farm 3, and, finally, 68% on farm 4.

The impact of production factors and irrigation plays a less significant role (<34% on all four farms considered).

Photochemical ozone formation (POF): the contribution of mechanisation is important in all 4 farms, where plowing, harrowing, and harvesting have an important influence on the results, with percentages ranging from 54% for farm 1, 82% for farm 2, 94% for farm 3, and finally 57% for farm 4. The other part of contribution is irrigation influencing this impact category, for example, hose irrigation on farm 4 has an impact of about 30% of the total, 5% for drip irrigation on farm 3, 16% for flood irrigation on farm 2, and finally 29% for pivot irrigation on farm 1. Finally, in this category, there is production factors impact only in farms 1 and 4 due to urea use, with an impact of 16% (farm 1) and 11% (farm 4).

Resource use, fossils (FRU): the four farms have similar impacts on mechanisation, where slurry distribution and harvesting have an important influence on the results. Respectively: for farm 1, slurry distribution contributes 5% and harvesting 13%, for farm 2: 32% and 18%, for farm 3: 41% and 17%, and finally for farm 4: 14% and 9%. Irrigation also has an important weight in this impact category, its contribution is most visible in farm 4 with hose irrigation with 27%, while less than 21% in the remaining three farms. As seen in some previous impact categories, the contribution of production factors on farms 1 and 4 with 41% and 34% respectively is not negligible.

Resource use, minerals and metals (MMRU): mechanisation in the MMRU impact category ranges from 40% on farm 1 to 84% on farm 2, 30% for farm 3, and 35% for farm 4. The major contributing operations are plowing with a contribution between 5 - 10%, harrowing between 2 - 5%, sowing between 4 – 8%, slurry and manure distribution between 4 – 11%, and finally harvesting between 3 – 6%. Irrigation has a major contribution in this impact category especially in farm 3 with drip irrigation contributing 67% with most of this impact resulting from the use of steel and iron in the manufacture of the pump and some pipelines. Production factors impacts are not negligible on farms 1 and 4 due to the use of urea seen above.

Water use (WU): regarding the water use, it is important to note that most of the contributions come from water used for irrigation, specifically: farm 1 - 98%, farm 2 - 95%, farm 3 - 74% and farm 4 - 75%. The remaining contribution is attributable to mechanisation with percentages less than 16%.

To provide an additional comparison among the farms and additional information about how the impact categories contribute to the environmental performances, the "Single point Environmental Footprint 3.1 (adapted) V1.00 / EF 3.1 normalisation and weighting set" was calculated. The single score results, reported in Figure 4 (and in Table S5), range from 103.98 points for Farm 3 (flood) to 38.70 points (- 37%) for Farm 3 (drip). The farm characterised by the flood irrigation presents the worst performance even if for most of the evaluated impact categories the impact is the smallest. For this farm, the "Water use" is by far the main contributor (74%) able to offset the small contribute of the other impact categories. "Water use" is the main contributor for all the farms, with a share of 21% in Farm 1 – pivot, 43% in farm 3 – drip and 21% in Farm 4 - Hose.

Sensitivity and uncertainty analysis

To test the robustness of the achieved environmental results, sensitivity and uncertainty analyses were carried out.

Sensitivity analysis

A sensitivity analysis was conducted to study the effect of key parameters, assumptions and methodological choices of the study. Thus, the following aspects were considered: biomass yield, mass allocation, energy requirements for irrigation and the characterisation method.

Biomass yield

Although the cultivation practice of maize cultivation is well known and standardised, productivity can be highly variable due to drought, pathogen attacks (*Ostrinia nubilalis* and *Diabrotica virgifera*), and adverse weather events during the summer season. Considering that yield ranges from 20.03 to 27.70 tons per hectare the sensitivity analysis was carried out considering the average yield (24.05 t/ha) for the 4 different cultivation practices.

The results of the sensitivity analysis are reported in Table S6 of the supplementary material. Yield variation affects all impact categories. Specifically, if the average yield is lower than the actual yield, as in Farms 1 and 3, the percentage variations in impacts worsen from 4.22% to 16.58% for Farm 1 and from 14.26% to 45.73% for Farm 3. Conversely, for Farms 2 and 4, where the average yield is higher than the actual yield, the percentage variations in impacts improve from 2.17% to

8.86% for Farm 2 and from 15.82% to 31.64% for Farm 4. It is important to note that 13 out of 14 categories show a percentage variation in line with the percentage variation of average yield, while marine eutrophication is the only category that deviates from this trend. In fact, in farms where the average yield is higher than the actual yield (Farms 2 and 4), the impact of marine eutrophication varies more than the yield variation on the average yield (-8.86% for Farm 2 and -31.64% for Farm 4). This occurs because the amount of mineral and organic fertilisers applied remains constant, but nutrient uptake by the plants increases to meet the higher yield, resulting in a decrease in nitrogen leaching. In farms where the average yield is lower than the actual farm yield (Farms 1 and 3), the impact of marine eutrophication varies more than the yield variation on the average yield (+16.58% and +45.73%), as the amount of mineral and organic fertilisers applied remains constant, but nutrient uptake by the plants decreases, leading to increased nitrogen leaching. As expected, the impact on environmental performance increases proportionally with the magnitude of the yield variation.

Mass allocation

Maize stalks are the by-product obtained after harvesting ear maize silage. They are the central and basal part of the maize plant, sturdy, fibrous stalks that provide structural support for the leaves and ears of maize. The stalks can be harvested and used as bedding for livestock or alternatively can be left on field and later buried to restore soil quality.
A sensitivity analysis was carried out assuming the harvesting of maize stalks on the 4 farms by carrying out two additional operations (stalks chopper and bailing) and resulting in bales of maize stalks weighing 600 kg each.

Generally, performing mass allocation for maize stalks the reduction ranges from 8.95% to 48.01% (Table S7).

For farm 1 with pivot irrigation, the impact of cultivation divided on a mass basis is as follows: 80.8% to the main product and 19.2% to the by-product.

For farm 2 with flood irrigation, the impact of cultivation divided on a mass basis is as follows: 72.2% to the main product and 27.8% to the by-product.

For farm 3 with drip irrigation, the impact of cultivation divided on a mass basis is as follows: 84.9% to the main product and 15.1% to the by-product.

For farm 4 with hose irrigation, the impact of cultivation divided on a mass basis is as follows: 83.3% to the main product and 16.7% to the by-product.

The impact reduction in farm 1 ranges from -14.00% in the Photochemical ozone formation category to -37.75% in the Eutrophication, marine category.

Impact reduction in farm 2 ranges from -19.18% in the Human toxicity - cancer category to -48.01% in the Eutrophication, marine category.

Impact reduction in farm 3 ranges from -8.95% in the Human toxicity - cancer category to -15.51% in the Eutrophication, marine category, with an average of -12.91%.

Finally, the impact reduction in farm 4 ranges from -13.80% in the Human toxicity - cancer category to -21.89% in the Eutrophication, marine category, with an average of -15.79%.

As expected, harvesting maize stalks results in a reduction of the environmental load on the main product for a twofold reason: first, by having a by-product, the environmental impact is divided among several products; second, this is also due to the share of nitrogen that is contained in maize stalks and that, being harvested and packed, is not left in the field and consequently the nitrogen is not leached into the soil. For this reason, the impact reduction of the categories considered is always lower than the by-product allocation percentage, except in the case of marine eutrophication, whose reduction value is always higher.

Energy requirements for irrigation

A sensitivity analysis was performed regarding the energy requirement for irrigation. For each irrigation method, this analysis considered a ±10% variation of the energy requirements for irrigation.

The results of the sensitivity analysis are presented in Table S8 in the supplementary material. Flood irrigation is the most sensitive to variations of energy requirement. Due to its high energy consumption (primarily diesel), even slight variations of energy use result in significant changes of the environmental results for some impact categories. The impact variation is higher than 5% for the following impact categories: (i) Resource Use – Fossils (+9.05% and -8.80% with 10% increase and decrease of energy consumption for irrigation, respectively); (ii) Photochemical ozone formation (+7.33% and -5.82% with 10% increase and decrease of energy consumption for irrigation, respectively).

Characterisation method: ReCiPe 2016 Midpoint (H) V1.08

To improve the comparability of the results, the inventory data was characterised using a different LCIA method. Beside the EF 3.1 method, the ReCiPe 2016 Midpoint (H) V1.08 (Huijbregts *et al*., 2017) was considered.

The environmental results are reported in Supplementary Materials (Table S9). A direct comparison between the environmental results achieved using the two LCIA methods cannot be done because different impact categories and different units were used. Nevertheless, the comparison shows similar results about the contribution analysis and about the identification of the best and worst solution for all the evaluated impact categories, moreover it allows comparison with other studies adopting this characterisation method.

Uncertainty analysis

An uncertainty analysis was performed on the comparison of the following irrigation methods: pivot-flood, pivot-drip, pivot-hose, flood-drip, flood-hose and finally hose-drip using the Montecarlo technique (1,000 interactions and a 95%

confidence interval) to test the robustness of results. The results of the uncertainty analysis are shown in Figures S1-S, where the left bars represent the probability that the environmental impact of the one irrigation method is less than the second one, while the right bars mean the opposite.

The results of the uncertainty analysis show that modelling of the environmental impact of different irrigation systems is suitable, environmental results are reliable for 9 impact categories assessed, except for impact categories relating to human toxicity and freshwater ecotoxicity (HT-c, HT-nc, FEx), the water use (WU) and climate change (CC). The high uncertainty observed in the toxicity-related impact categories is due to the significant variability in characterisation factors of the active ingredients of pesticides. This implies that, for some specific comparisons between irrigation methods, for HT-noc, HT-c and FEx, the confidence level is lower than 80%, suggesting the need for further investigation to improve the robustness of the assessments in these impact categories.

The level of statistical significance is less than 80% for the comparison between:

- Pivot and Flood: with the pivot showing higher impact respect to the flood irrigation system with a statistical significance level of 51% for HT-nc, of 54% HT-c and of 64% for CC;

- Pivot and Drip: with the drip showing higher impact respect to the pivot irrigation system with a statistical significance level of 51% for HT-nc and of 64% for WU. In contrast, the pivot shows higher impact of drip irrigation with a statistical significance level of 57% for HT-c;

- Pivot and Hose: with the hose showing higher impact respect to the pivot irrigation system with a statistical significance level of 53% for HT-nc, of 55% for HT-c, of 64% for WU and of 70% for FEx;

- Flood and Drip: with the drip showing higher impact respect to the flood irrigation system with a statistical significance level of 52% for HT-nc, of 53% for HT-c, of 70% for FEx. In contrast, the flood shows higher impact of drip irrigation with a statistical significance level of 77% for FEx;

- Hose and Flood comparison: with the hose showing higher impact respect to the flood irrigation system with a statistical significance level of 51% for HT-nc and of 53% for HT-c;

- Hose and Drip comparison: with the hose showing higher impact respect to the drip irrigation system with a statistical significance level of 51% for HT-nc and of 53% for HT-c. In contrast, the drip shows higher impact of hose irrigation with a statistical significance level of 51% for WU.

The impact categories showing a higher uncertainty are the toxicity-related ones. This is due to the characterisation factors that for these impact categories show high variability respect to the default value (the mean).

Discussion

In this study, using LCA, the environmental consequences associated with different irrigation methods in maize cultivation were evaluated. In this way, the main critical points and environmental benefits of maize cultivation were quantified. In detail, the impact on climate change of maize cultivation was mainly due to mechanisation of crop operations (19-21%) and nitrous oxide (50-67%) emitted with the use of organic and mineral fertilisers.

Comparing the results of different LCA studies is not always possible, mainly because different system boundaries and functional units are used, and different methodological assumptions are made (e.g., the model used to estimate emissions, etc.). Nevertheless, the analysis of contributions in this study shows similar results to other maize-focused LCA studies. In particular, Bacenetti *et al. (2013)* and Dressler *et al. (2012)* identified mechanisation and nitrous oxide as the main contributors to climate change.

The main driver of the environmental impacts is the yield, however, the role of irrigation cannot be overlooked also because, although not explicit and easily quantifiable, the relationship between irrigation and yield is relevant.

Regarding mechanical operations, the results of this study indicate that the use of slurry or liquid digestate distribution techniques with direct injection and rapid incorporation into the soil offers numerous environmental benefits, especially when compared with the splash plate spreading method, in accordance with the findings by Bacenetti *et al., (2016)*. These benefits are evident in the impact categories affected by ammonia emissions, such as PM, A, and TE.

Bacenetti *et al.,* (2016) also pointed out that without accurate calculations to determine available space and amounts to be spread, there is a risk of reducing ammonia volatilisation but increasing nitrogen leaching, negatively affecting ME. On the four farms of this study, organic fertilisation was always carried out in March, about a month before maize seeding. This approach significantly reduced nitrate leaching and phosphorus leaching, phenomena that mainly occur when these operations are carried out before the winter season (when the soil is bare).

As shown in the results of this research, the production and use of nitrogenous fertilisers and their field emissions are ranked among the top polluters in farming, and the farming process producing the highest emissions (Smith *et al. 2007;* Hasler *et al. 2015*). These conclusions are in line with a previous study focused on the cultivation of silage maize and other alternative crops (Bernas *et al., 2019b*).

On the other hand, while chemical crop protection and pesticide fate are crucial factors to consider in agricultural life cycle assessments (Bessou *et al., 2013*), their impact appears to be relatively minor in this study. However, pesticide fate assessment is very challenging, and understanding the effects of pesticide metabolites on environmental components requires extensive long-term field monitoring (*Vašíčková et al., 2019*). In addition, it is essential to consider the characteristics of pesticides and their active substances. In this study, chemical protections for maize cultivation, herbicides, and pesticides were considered.

Lastly, as mentioned above, water use in maize cultivation is a crucial factor in ensuring a good production yield. Significant effects of climate change on both mean precipitation and variability, with relevant consequences on water availability and crop production, are reported in many studies (Giorgi and Lionello*, 2008;* Sheffield and Wood*, 2008*). With increasing water scarcity, there is the need to optimise water use, mainly for irrigation purposes (Pereira *et al., 2009*). Thus, as argued in Irfan *et al., 2014* it is important to use sustainable irrigation techniques, such as drip irrigation or the use of water management systems that optimise water use, minimising environmental impact and maximising efficiency in maize production.

As reported by Bocchiola *et al., (2013)*, in the worst-case and most likely future scenarios in the Po Valley of Italy, with increasing temperature and decreasing precipitation, crop yields decreased and the water footprint increased, due to increased evapotranspiration, higher irrigation demand, and lower final yield. Although increased CO_2 may increase water use efficiency, it does not appear to significantly affect the water footprint. Any increase in rainfall could partially offset the increase in temperature, especially in a scenario of no or little irrigation, further reducing the water footprint.

Conclusions

In this study, the production of ear maize in 4 farms characterised by four different irrigation systems was analysed and compared for their environmental impact through LCA. The identification of the best irrigation method is affected by other parameters such as the crop productivity. Depending on the evaluated impact category, the less impacting irrigation method changes. In detail, for water use, drip irrigation, the method with the highest irrigation efficiency, is the best performing but at the same time, shows the worst results for most of the other impact categories due to the significant use of disposable plastic.

To improve the sustainability of this important operation, current research is going in the direction of improving the environmental performance of maize production through solutions aimed at saving water, such as the development of mobile applications that provide real-time information on the crop water status, hence reducing the interventions needed and enabling more precise water monitoring. Lastly, there is also a need of developing strategies that reduce fossil fuel consumption and emissions from fertiliser use, both organic and mineral. It is important to integrate multiple mitigation strategies that can simultaneously act on different environmental impacts wherever possible.

In this context, this study provides useful information about the environmental impact of alternative irrigation methods for maize cultivation. Nevertheless, considering that the main driver of the environmental results is the crop productivity, the relationship between crop yield and water availability should be more deeply investigated to identify the best irrigation method also in the context of the future water shortages.

Acknowledgments

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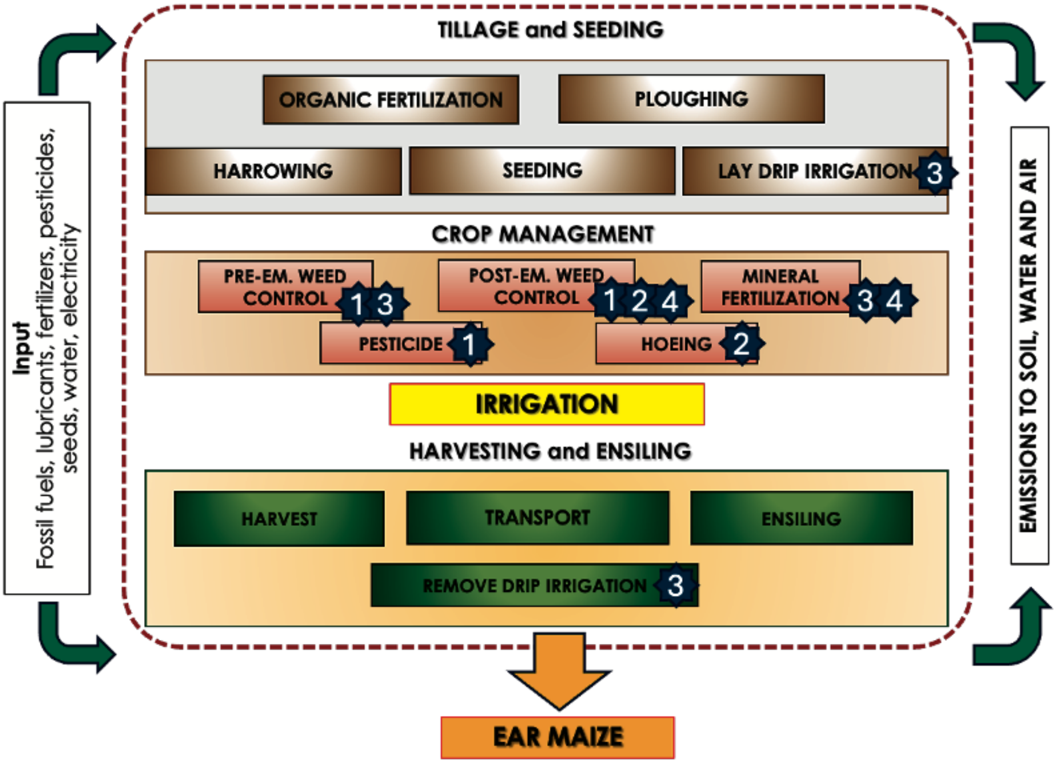


Figure 1. System boundaries. Numbers 1-4 refer to the single farms operations, as follows: 1: operation carried out only in farm 1; 2: operation carried out only in farm 2; 3: operation carried out only in farm 3; 4: operation carried out only in farm 4.

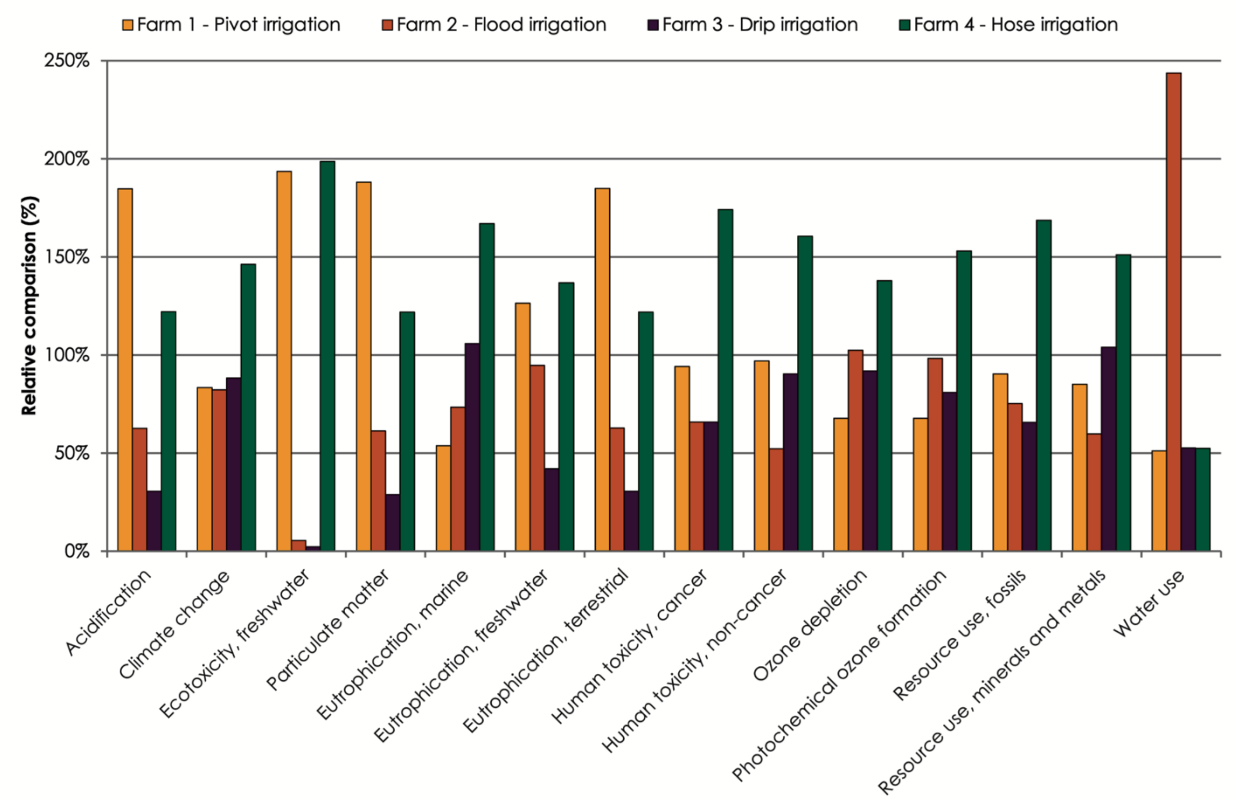
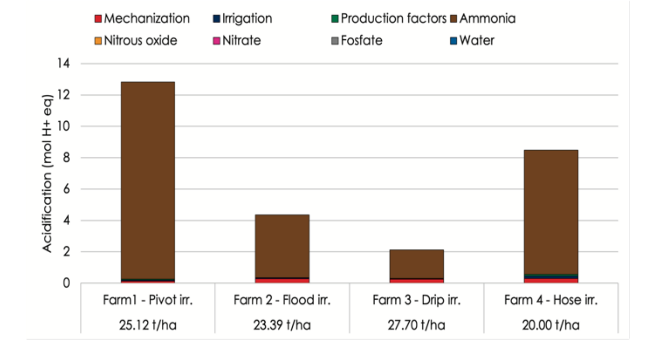
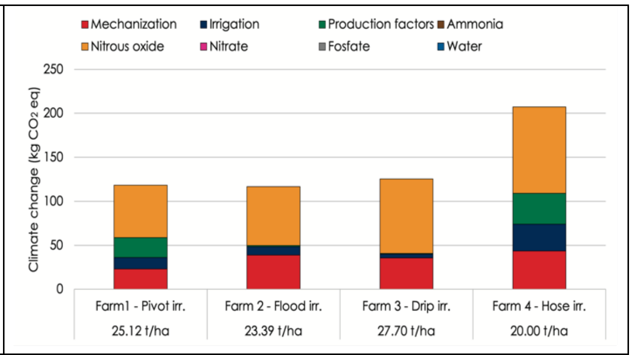


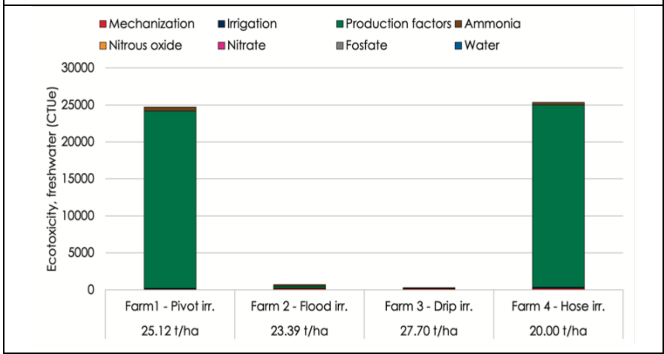
Figure 2. Relative comparison of normalisation among different cultivation practices characterised by the 4 different irrigation methods.



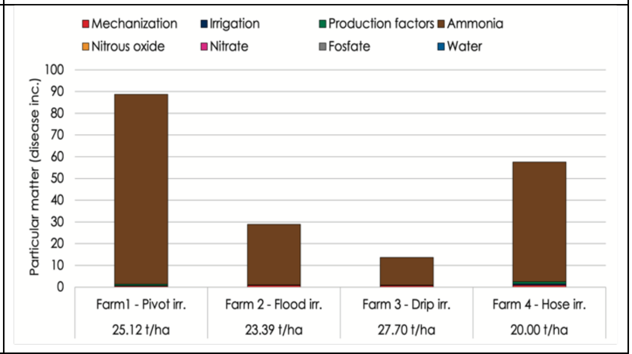
a) Acidification (A)



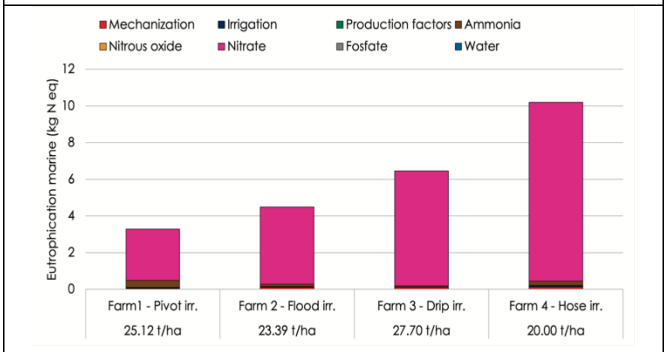
b) Climate change (CC)



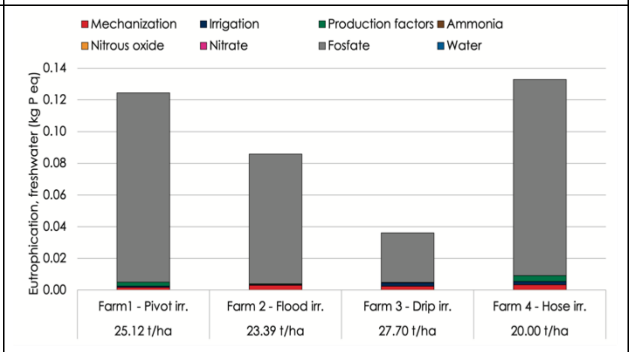
c) Ecotoxicity, freshwater (FEx)



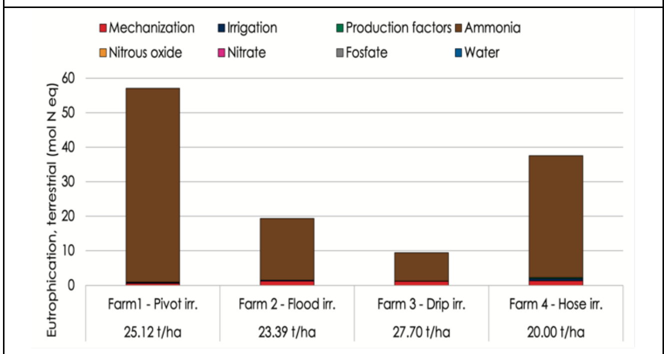
d) Particulare matter (PM)



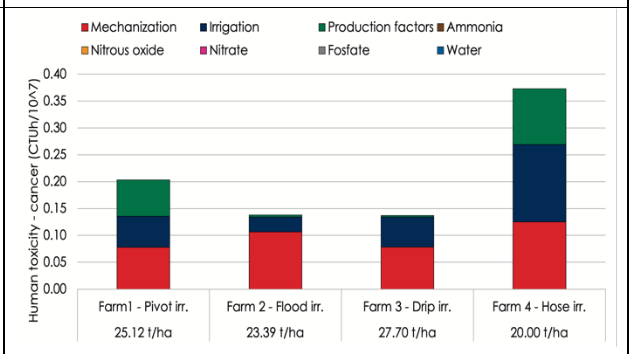
e) Eutrophication marine (ME)



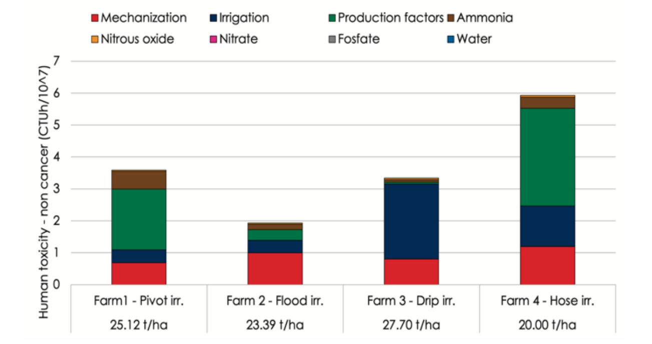
f) Eutrophication, freshwater (FE)



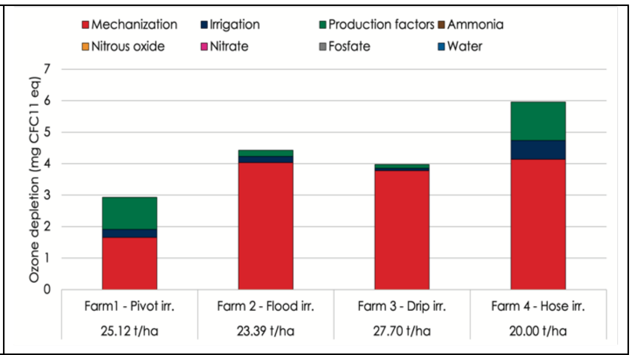
g) Eutrophication, terrestrial (TE)



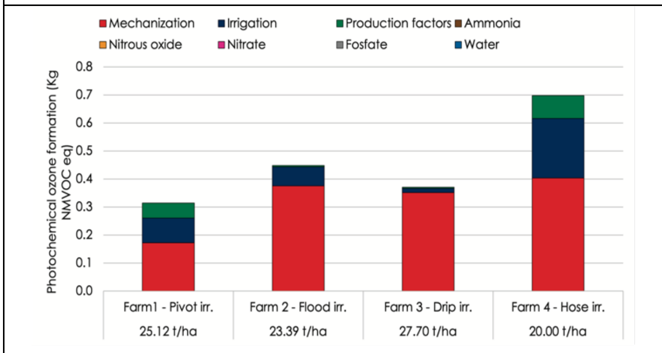
h) Human toxicity – cancer (HT-c)



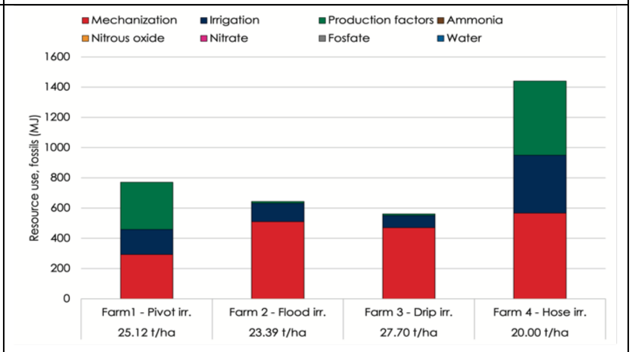
i) Human toxicity – non cancer (HT-nc)



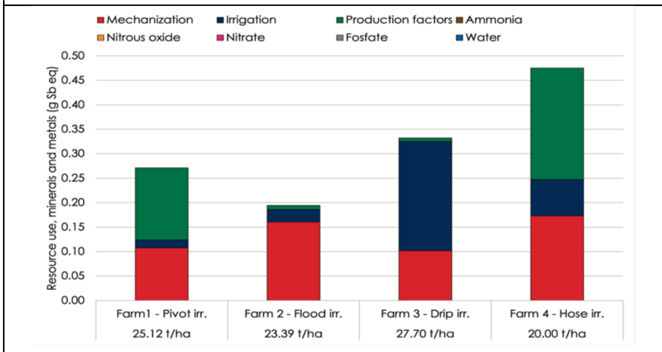
j) Ozone depletion (OD)



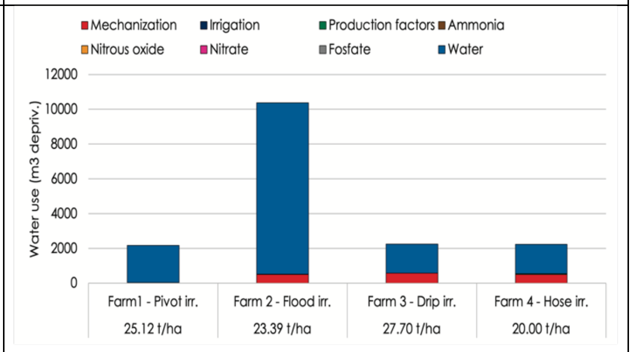
k) Photochemical ozone formation (POF)



l) Resource use, fossils (FRU)



m) Resource use, minerals and metals (MMRU)



n) Water use (WU)

Figure 3. Results of the contribution analysis for the different impact categories.

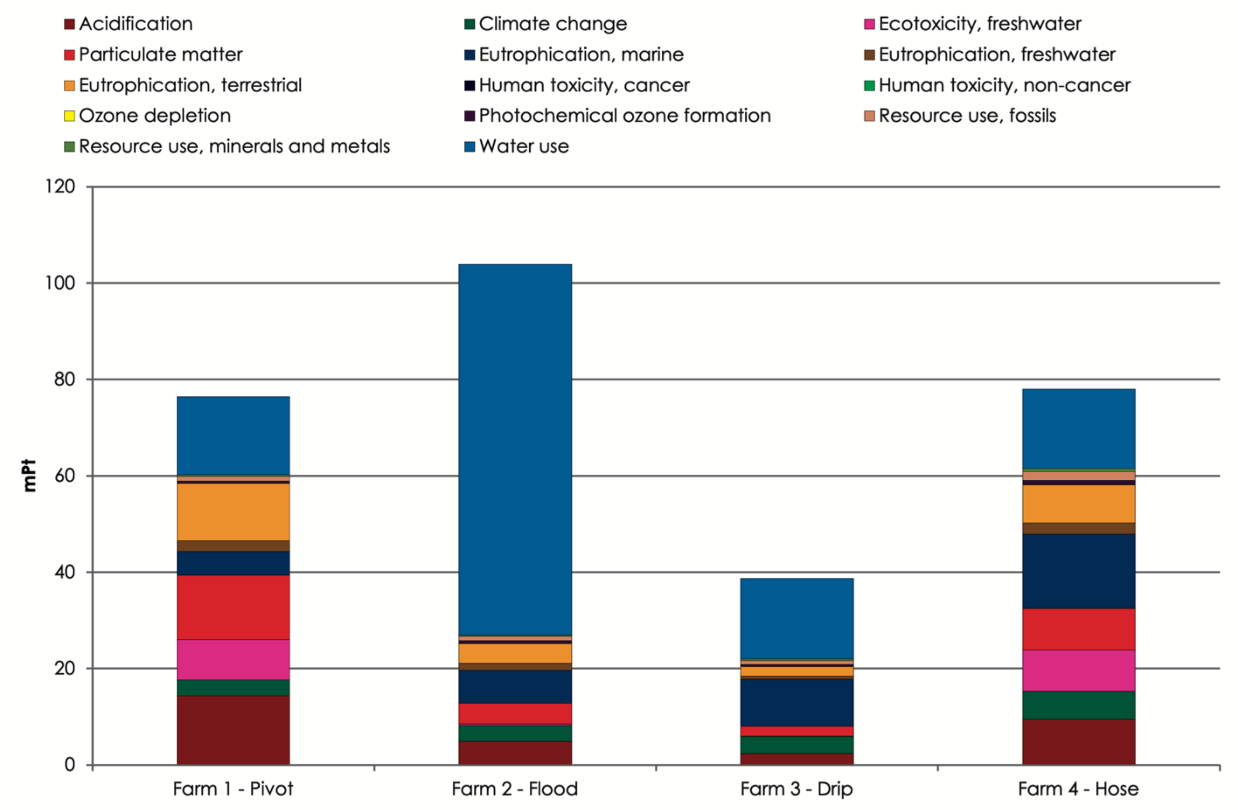


Figure 4. Single point Environmental Footprint 3.1 (adapted) V1.00 / EF 3.1 normalisation and weighting set.

Table 1. Typology of cultivated maize (variety and FAO class), and irrigation method adopted in each of the studied farms.

Farm	Variety	FAO class	Irrigation method	Irrigation efficiency	Yield (t/ha)
1	Limagrain - LG 31700	700	Pivot	85%	25.12
2	Pioneer - P 0900	500	Flood	55%	23.39
3	Pioneer - P 0900	500	Drip	95%	27.70
4	Pioneer - P 0937	500	Hose	75%	20.03

Table 2. Cultivation practice: field operations and production factor consumed – Farm 1.

Section	Operation	Input (other than diesel)	Amount
(1) Soil tillage and seeding	Organic fertilisation	Cattle manure (N 0,4%)	80 t/ha
	Ploughing		
	Harrowing		
	Seeding	Seeds	20 kg/ha
(2) Crop management	Weed control pre germination	Isoxaflutole Thiencarbazone-methyl Cyprosulfamide	0.4 l/ha
	Weed control post germination	Nicosulfuron	0.25 l/ha
		Dicamba	1 l/ha
	Mineral fertilisation	Urea	250 kg/ha
	Pesticide (2 repetitions)	Deltametrina	0.5 l/ha
		Cymoxanil	
		Folpet	0.1 l/ha
		Fosetil	
(3) Harvesting and ensiling	Harvesting		
	Transport		
	Ensiling		

Table 3. Environmental impact for all farms (FU = 1 ton of ear maize). For each impact category, greener patterns indicate lower impacts (best performing farms) while redder patterns indicate higher impacts (worst performing farms).

		Unit	Farm 1 - Pivot – 25.12 t/ha	Farm 2 – Flood – 23.39 t/ha	Farm 3 – Drip – 27.70 t/ha	Farm 4 - Hose – 20.03 t/ha
Impact category	Acidification	mol H+ eq	12.83	4.35	2.13	8.48
	Climate change	kg CO_2 eq	118.38	116.66	125.36	207.42
	Ecotoxicity, freshwater	CTUe	24724.17	697.53	285.33	25369.09
	Particulate matter	Dis. inc./10^6	88.79	28.93	13.63	57.53
	Eutrophication, marine	kg N eq	3.29	4.48	6.46	10.2
	Eutrophication, freshwater	kg P eq	0.12	0.09	0.04	0.13
	Eutrophication, terrestrial	mol N eq	57.04	19.37	9.42	37.57
	Human toxicity - cancer	CTUh/10^7	0.2	0.14	0.14	0.37
	Human toxicity - non cancer	CTUh/10^7	3.58	1.93	3.34	5.93
	Ozone depletion	mg CFC11 eq	2.93	4.43	3.97	5.96
	Photochemical ozone form.	kg NMVOC eq	0.31	0.45	0.37	0.7
	Resource use, fossils	MJ	771.57	643.86	561.41	1439.94
	Res. use, minerals and metals	g Sb eq	0.27	0.19	0.33	0.48
	Water use	m^3 depriv.	2178.29	10380.65	2243.43	2233.85