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Abstract

The aim of the study was to quantify site-specific secondary data of mechanical field operations for EU barley cropping. By the model ENVIAM v2, each operation was subdivided into 13 working times and, for each of them, the amount of total consuming inputs (fuel, lubricant and AdBlue®) and emissions of exhaust gases into the atmosphere were calculated. The amount of partial consuming inputs (machinery mass) and emissions of heavy metals into the soil were also quantified. Three scenarios (S) were identified: S_1 = 50 ha, S_2 = 100 ha, S_3 = 200 ha, with the same: agronomic conditions, operations sequence, type of machines used and cropping inputs. For each scenario, two barley ideotypes were analyzed: (i) currently in use (BarNow, 2018) and (ii) future (BarPlus, 2030). BarPlus is characterized by: (i) higher grain and straw yield, Nitrogen fertilization rate and machinery Effective Field Capacity, (ii) use of TIER 5 fuel engines, (iii) lower minimum specific fuel consumption. BarNow inputs ($kg \cdot ha^{-1}$) were: fuel = 67 ÷ 74, lubricant = 0.56 ÷ 0.73, mass = 7.9 ÷ 8.8. BarPlus inputs ($kg \cdot ha^{-1}$) were: fuel = 55 ÷ 60, lubricant = 0.53 ÷ 0.69, AdBlue® = 2.8 ÷ 3.0, mass = 7.2 ÷ 8.0. The highest fuel and mass consumptions were in both cases related to tillage operations.

Keywords: Barley cultivation - Mechanical field operation - Working time - Site-specific secondary data - Environmental inventory

High Accuracy Site-Specific Secondary Data for Mechanical Field Operations to Support LCA Studies

Marco Fiala and Luca Nonini

Abstract The aim of the study was to quantify site-specific secondary data of mechanical field operations for EU barley cropping. By the model ENVIAM v2, each operation was subdivided into 13 working times and, for each of them, the amount of total consuming inputs (fuel, lubricant and AdBlue®) and emissions of exhaust gases into the atmosphere were calculated. The amount of partial consuming inputs (machinery mass) and emissions of heavy metals into the soil were also quantified. Three scenarios (S) were identified: $S_1 = 50$ ha, $S_2 = 100$ ha, $S_3 = 200$ ha, with the same: agronomic conditions, operations sequence, type of machines used and cropping inputs. For each scenario, two barley ideotypes were analyzed: (i) currently in use (BarNow, 2018) and (ii) future (BarPlus, 2030). BarPlus is characterized by: (i) higher grain and straw yield, Nitrogen fertilization rate and machinery Effective Field Capacity, (ii) use of TIER 5 fuel engines, (iii) lower minimum specific fuel consumption. BarNow inputs ($\text{kg}\cdot\text{ha}^{-1}$) were: fuel $= 67 \div 74$, lubricant $= 0.56 \div 0.73$, mass $= 7.9 \div 8.8$. BarPlus inputs ($\text{kg}\cdot\text{ha}^{-1}$) were: fuel $= 55 \div 60$, lubricant $= 0.53 \div 0.69$, AdBlue® $= 2.8 \div 3.0$, mass $= 7.2 \div 8.0$. The highest fuel and mass consumptions were in both cases related to tillage operations.

Keywords Barley cultivation · Mechanical field operation · Working time · Site-specific secondary data · Environmental inventory

1 Introduction

The most widespread methodology to quantify the potential environmental impacts of agricultural processes is the Life Cycle assessment (Life Cycle Analysis, LCA) (Notarnicola et al. 2017). Among the LCA phases, the Life Cycle Inventory (LCI) is the most complex to accomplish because all the system inputs (fuel, lubricant,

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masses) and outputs (emissions into the atmosphere, water and soil) have to be identified and quantified. Often, these data are not easy to collect experimentally, and long and expensive sampling are needed (Dyer and Desjardins 2003; Ossés de Eicker et al. 2010). To limit this problem, many commercial Databases that provide information about different agricultural processes (e.g. Ecoinvent, Danish LCA food, EU and DK input and output Database, Agri-footprint Database) were developed (Jannick et al. 2010; Ecoinvent 2015). Nevertheless, they usually provide simplified information about some processes and, therefore, their main deficiency is the lack of reliability. This represents a major problem for mechanical field operations, which are performed in very different conditions, both pedological (texture, water content, slope, shape and size of the field and its distance from the farm), and climatic (temperature and rainfall) (Lovarelli et al. 2016, 2017). Mechanical field operations play a crucial role in determining the environmental impacts of agricultural processes (Keyes et al. 2015) but, due to the abovementioned problems, performing reliable LCA studies using site-specific primary data is a key challenge. Therefore, it is necessary to develop models able to calculate secondary data with high accuracy, according to the different site-specific conditions (Bengoa et al. 2014). Several studies were performed to evaluate the environmental impacts of cereal cropping (Murphy and Kendall 2013; Achten and Van Acker 2016), including those related to barley cultivation (Dijkman et al. 2017). Barley is a great source of nutrients, carbohydrates and fiber (Baik and Ullrich 2008), and it is primarily used for animal feedstock and malt production (Schmidt Rivera et al. 2017). This crop is the 12th most important agricultural commodity in the world, and Europe is the largest producer (62% of the world production) (FAO, 2016). The aim of the study was to quantify site-specific secondary data related to mechanical field operations for EU barley cropping (from soil tillage to grain and straw transport) to support LCA studies.

2 Materials and Methods

2.1 The Model ENVIAM V2

The model ENVIAM v1 ("ENVironmental Inventory of Agricultural Machinery operations") was developed some years ago (Lovarelli et al. 2016) to calculate site-specific secondary data related to mechanical field operations, by taking into account specific working times (t_j; h) (Reboul 1964). These data refer to both the amount of total (fuel and lubricant) and partial (mass of machinery) consuming inputs, as well as the emissions of exhaust gases (CO_2, CO, HC, PM and NO_x) into the atmosphere, resulting from fuel combustion. ENVIAM v1 was recently implemented into a second version (ENVIAM v2); the main improvements are: (i) calculation of the working times (13 in total) in separate worksheets, specifically developed for each type of implement used. To make the further calculations feasible and accurate, a value of engine load (λ; % tractor's maximum engine power) must be assigned to each working time. This is a fundamental step, since fuel consumptions—and thus exhaust gases emissions into the atmosphere—strongly depend on both tractor's engine loads and duration of each working time (Lovarelli et al. 2018). The time for transfer farm-to-field and field-to-farm (including the one for lunch breaks) was included in the calculation: it cannot be neglected for operations carried out over one day and for long distances between the farm center and the fields; (ii) calculation of AdBlue® consumption if the tractor is equipped with a Selective Catalyst Reduction (SCR) system; (iii) calculation—for tractors—of the mass required for production, consumption, maintenance and repair, by introducing a repair factor according to the Ecoinvent v3.2® Database documentation (Nemecek and Kägi 2007); (iv) calculation of the mass of tire abraded during the operation and the corresponding mass of heavy metals (Cd, Pb, Zn) released into the soil (Nemecek and Kägi 2007); (v) improvement of the general structure of the model, by removing some demanding tests, to provide a more intuitive and user-friendly interface. Other aspects are instead still under investigation: (i) calculation of the tractor's engine power losses in the case of hydraulic/mixed transmissions and (ii) calculation of consumptions and emissions for operations performed under slope conditions.

2.2 Barley Cultivation Scenarios

The analysis was based on the following assumptions about barley production in Europe: (i) the crop is cultivated on a wide range of farms whose Agricultural Area Used (AAU; ha) ranges from a few tens to a hundred hectares (European Commission 2018); (ii) the sequence of mechanical field operations is simplified compared to other herbaceous crops and involves the use of the same types of machines; (iii) the production factors (inputs) are limited in terms of both quality and quantity (Marinussen et al. 2012); (iv) the crop is not irrigated (barley has a good resistance to drought and, usually, uses only natural water supplies); (v) grain (Y_G; $t{\cdot}ha^{-1}$) and straw (Y_S; $t{\cdot}ha^{-1}$) yields show limited variations among different cultivation areas (Marinussen et al. 2012). Three different scenarios (S) were compared (Fiala et al. 2019): (i) S1: small size cereals production farm ($AAU_1 = 50$ ha); (ii) S2: medium size cereals production farm ($AAU_2 = 100$ ha); (iii) S3: medium-large size cereals production farm ($AAU_3 = 200$ ha). These scenarios are all characterized by the same: (i) cultural conditions (fields shape, distance from the farm center); (ii) cultivation operations timeline and type of machines used and (iii) cropping input (Table 1).

Tractors and implements technical characteristics concern EU agricultural machinery market; cropping inputs amounts refer to EU conditions. S1, S2 and S3 scenarios were different for the tractor (number, type, engine power) and the implements (size) fleet. For each scenario, two barley ideotypes were taken into account: (i) currently in use (year 2018, BarNow, $S1_{NOW}$, $S2_{NOW}$, $S3_{NOW}$) and (ii) a future ideotype (year 2030, BarPlus; $S1_{PLUS}$; $S2_{PLUS}$, $S3_{PLUS}$). BarNow and BarPlus cultivations were compared by introducing, for the latter, cropping and technological improvements.

Table 1 Agronomic parameters used for the different scenarios

	Unit	S1	S2	S3
Agricultural area used	ha	$AAU_1 = 50$	$AAU_2 = 100$	$AAU_3 = 200$
Barley area (60% AAU)	ha	$AAU_{B1} = 30$	$AAU_{B2} = 60$	$AAU_{B3} = 120$
Other crops (35% AAU)	ha	$AAU_{O1} = 17.5$	$AAU_{O2} = 35$	$AAU_{O3} = 70$
Green crops (5% AAU)		$AAU_{G1} = 2.5$	$AAU_{G2} = 5$	$AAU_{G3} = 10$
Fields distance	km	D = 2.0		
Fields characteristics	–	Soil texture: medium; area: flat; shape: rectangular		
Fields length	m	$b_L = 800$		
Cropping sequence	–	(1) NPK fertilization, (2) ploughing, (3) harrowing, (4) sowing, (5) chemical weed control, (6) N fertilization, (7) grain harvesting and (8) transport, (9) straw collection and (10) transport		
Cropping inputs	$kg{\cdot}ha^{-1}$	Seeding rate: 190; herbicide rate: 1.45		

Table 2 BarNow and BarPlus scenarios: grain and straw characteristics and yields

Product	BarNow (year 2018)		BarPlus (year 2030)	
	Dry matter (%)	Yield ($t{\cdot}ha^{-1}$) ($t{\cdot}ha^{-1}$ DM)	Dry matter (%)	Yield ($t{\cdot}ha^{-1}$) ($t{\cdot}ha^{-1}$ DM)
Grain	$DM_G = 81.5\%$	$Y_G = 6.5$ (5.3)	$DM_G = 88.0$	$Y_G = 7.5$ (6.6)
Straw	$DM_S = 84.5\%$	$Y_S = 6.5$ (5.5)	$DM_S = 86.3$	$Y_S = 7.3$ (6.3)

2.2.1 Cropping Improvements

Grain and straw yield and dry matter (DM) content of both barley ideotypes are shown in Table 2.

The improvement of the performance of the BarPlus ideotype was pointed out in the Project "*BARPULS—Modifying canopy architecture and photosynthesis to maximize barley biomass and yield for different end-uses*" (EU FACCE-SURPLUS ERA-NET, 2015–2018). According to the results of this Project—which takes into account future climate changes in EU, as well as the evolution of barley genotype and phenotype—the increase of the biomass yield (for both grain and straw) can be achieved by a higher rate in Nitrogen mineral fertilization ($\Delta N = 20\ kg{\cdot}ha^{-1}$ of N) (Table 3).

2.2.2 Technological improvements

Compared to BarNow, for the BarPlus scenarios the following improvements were considered (Table 4): (i) use of internal combustion (i.c.) fuel engines at TIER 5 (Emission Stage V, in force since January 2019); (ii) reduction of NO_x emissions

Table 3 BarNow and BarPlus scenarios: NPK requirements and fertilizer rates (R)

Agronomic aspects	Unit	BarNow (year 2018)	BarPlus (year 2030)
Requirements	kg·ha^{-1}	(N) 100; (K_2O) 20; (P_2O_5) 40	(N) 120; (K_2O) 20; (P_2O_5) 40
1st mineral fert.	kg·ha^{-1}	R_1 = 150 (NPK 20-20-20)	R_1 = 150 (NPK 20-20-20)
2nd mineral fert.	kg·ha^{-1}	R_2 = 220 Urea (46%)	R_2 = 265 Urea (46%)

Table 4 BarNow and BarPlus scenarios: technological improvements in fuel engines

Technical aspects	Unit	BarNow (year 2018)	BarPlus (year 2030)
Emission stage	–	TIER 3B	TIER 5
Equipment	–	None	SCR and AdBlue® (#)
Specific fuel consumption	g·kWh^{-1}	cs_{MIN} = 200 ÷ 250	Δcs_{MIN} = − 10%

Note: (#) AdBlue® consumption = 5% of fuel consumption

into the atmosphere (use of SCR systems and AdBlue®); (iii) decrease of 10% of the specific minimum fuel consumption (cs_{MIN}; g·kWh^{-1}), due to improved performance of i.c. engines (Diesel cycle, in particular).

In addition, for the BarPlus scenarios, due to the technological innovations in the agricultural machinery sector, an increase of the Effective Field Capacity (EFC; ha·h^{-1}) of the implements was introduced: ΔEFC = +10% for less complex machines (shovels plough, rotary harrow, dumper for grain and trailer for straw) and ΔEFC = + 15% for more complex ones (mineral fertilizer spreader, row seeder, herbicide sprayer, combine harvester and round baler).

2.2.3 S1, S2, S3 Machines (Tractors and Implements)

Information about the tractor fleets of S1, S2 and S3 scenarios are shown in Table 5.

For all scenarios, the following implements were used: n.1 mineral fertilizer spreader, n.1 shovel plow, n.1 rotary harrow, n.1 row seeder (mechanical type for S1; pneumatic type for S2 and S3), n.1 herbicide sprayer, n.1 combine harvester, n.1 dumper (for grain transport), n.1 baler (round bales), n.1 trailer (for straw transport). It was assumed that all the operations were carried out by using farm machines, except for grain harvesting (n.1 combine harvester), carried out by a contractor.

Table 5 S1, S2 and S3 scenarios: farm tractor fleets

	Farm tractor fleet				
Scenario	Number and type	Power range (kW)	Total power (kW)	Mechanization index ($kW \cdot ha^{-1}$)	Annual use ($h \cdot year^{-1}$)
S1	3 4WD, 1 2WD	30–100	240	$Pm_{AAU1} = 4.8$	$H_{n1} = 1000$
S2	4 4WD, 1 2WD	50–150	400	$Pm_{AAU2} = 4.0$	$H_{n2} = 1000$
S3	6 4WD, 1 2WD	50–200	780	$Pm_{AAU3} = 3.9$	$H_{n3} = 1000$

3 Results and Discussion

The Total Time (T_{TOT}; h) spent for barley cultivation in the different scenarios were:

- S1: T_{TOT1} = 226 h and 209 h, for $S1_{NOW}$ and $S1_{PLUS}$, respectively. Consequently, the whole machinery chain Effective Field Capacity (EFC_1) increases from 0.13 $ha \cdot h^{-1}$ ($S1_{NOW}$) to 0.14 $ha \cdot h^{-1}$ ($S1_{PLUS}$);
- S2: T_{TOT2} = 304 h and 281 h, for $S2_{NOW}$ and $S2_{PLUS}$, respectively. The whole machinery chain Effective Field Capacity (EFC_2) increases from 0.20 $ha \cdot h^{-1}$ ($S2_{NOW}$) to 0.21 $ha \cdot h^{-1}$ ($S2_{PLUS}$);
- S3: T_{TOT3} = 461 h and 430 h, for $S3_{NOW}$ and $S3_{PLUS}$, respectively. The whole machinery chain Effective Field Capacity (EFC_3) increases from 0.26 $ha \cdot h^{-1}$ ($S3_{NOW}$) to 0.28 $ha \cdot h^{-1}$ ($S3_{PLUS}$).

The EFC_3 is practically double compared to EFC_1; moreover, within each scenario, the EFC related to S_{PLUS} is only 5–8% higher than the EFC related to S_{NOW}.

Fuel consumption—and thus the emissions of exhaust gases into the atmosphere—strongly depend on both tractor's engine loads and duration of each working time. The widespread assumption that engine load is constant (generally, close to 80%) for each working time (that means to assume a constant low specific fuel consumption during the whole field operation), often leads to underestimate the emissions of exhaust gases into the atmosphere.

Inputs and emissions of exhaust gases into the atmosphere amounted to ($kg \cdot ha^{-1}$):

- BarNow scenarios: fuel FC = 67 ÷ 74, lubricants LC = 0.56 ÷ 0.73, mass MC = 7.9 ÷ 8.8, emissions of CO EM_{CO} = 0.37 ÷ 0.61, emissions of HC EM_{HC} = 0.09 ÷ 0.11, emissions of NO_x EM_{NOx} = 1.11 ÷ 1.62, emissions of PM EM_{PM} = 0.01 ÷ 0.02, emissions of CO_2 EM_{CO2} = 210 ÷ 232;
- BarPlus scenarios: fuel FC = 55 ÷ 60, lubricants LC = 0.53 ÷ 0.69, AdBlue® AdB = 2.8 ÷ 3.0, mass MC = 7.2 ÷ 8.0, emissions of CO EM_{CO} = 0.29 ÷ 0.47, emissions of HC EM_{HC} = 0.08 ÷ 0.10, emissions of NO_x EM_{NOx} = 0.22 ÷ 0.33, emissions of PM EM_{PM} = 0.01 ÷ 0.02, emissions of CO_2 EM_{CO2} = 174 ÷ 189.

The highest fuel (i.e. CO_2 emissions) and mass consumptions are—in any scenario—related to soil tillage (ploughing) operations (hotspot). Even if the results seem to be similar to those obtained by Niero et al. (2015), Dijkman et al. (2017) and Schmidt Rivera et al. (2017), it is not possible to do an absolute comparison because of the specificity of the methodology used in this study.

4 Conclusions

Although the use of primary data is always preferable to perform reliable LCA analysis, the collection of this type of data can be expensive and time-consuming. An alternative is the use of secondary data, related to the local working conditions, calculated by using specific models. In this study the model ENVIAM v2 was applied to calculate site-specific secondary data related to the mechanical field operations for barley cropping in EU conditions. The correct tractor-implement coupling is essential to assess the environmental performances of barley cultivation, especially if—as in this study—high accuracy calculations based on the relation between engine loads and working times are performed. By using ENVIAM v2—and commercial software—it is possible:

- to produce accurate local inventories containing complex information (mainly consumptions and emissions), thanks to the possibility of choosing—among the set of tractors and implements defined in the model—the coupling that best simulates the local working conditions;
- to quantify the potential environmental impacts associated with the whole production cycles. The data provided by ENVIAM v2 can be used to carry out an LCA analysis focused on one specific operation or on the full sequence of operations composing the crop cycle. Therefore, it is possible to identify the phases (or operations) to which the highest potential impacts on the environment are associated (hotspots);
- to identify mitigation solutions: this means to re-analyze the system assuming, on one hand, to use different machines to achieve the same goal and, on the other hand, to re-define the sequence of the mechanical field operations. In the first case, different machines designed to perform the same operation could be associated with different working times, consumptions and emissions, whereas, in the second case, the same agrotechnical objective can be achieved with a different sequence of operations, making it possible to define strategies (at the farm or landscape level) with lower potential environmental impacts.

AQ1

References

Achten, W. M. J., & Van Acker, K. (2016). EU-Average impacts of wheat production. A meta-analysis of life cycle assessments. *Journal of Industrial Ecology 20*(1), 132–144.

Baik, B. K., & Ullrich, S. E. (2008). Barley for food: characteristics, improvement, and renewed interest. *Journal of Cereal Science, 48*(2), 233–242.

Bengoa, X., Rossi, V., Humbert, S., Nemecek, T., Lansche, J., & Mouron, P. (2014). Methodological guidelines for the life cycle inventory of agricultural products. Version 2.0, July 2014. World food LCA database. *Quantis and Agroscope, Lausanne and Zurich, Switzerland*, 1–79.

Dijkman, T. J., Birkved, M., Saxe, H., Wenzel, H., & Hauschild, M. Z. (2017). Environmental impacts of barley cultivation under current and future climatic conditions. *Journal of Cleaner Production, 140,* 644–653.

Dyer, J. A., & Desjardins, R. L. (2003). Simulated farm fieldwork, energy consumption and related greenhouse gas emissions in Canada. *Biosystems Engineering, 85*(4), 503–513.

Ecoinvent (2015). Ecoinvent database. http://www.ecoinvent.org/database/.

European Commission (2018). Eurostat handbook for annual crop statistics, revision 2018. https://ec.europa.eu/eurostat/cache/metadata/Annexes/apro_cp_esms_an1.pdf.

FAOSTAT (2016). Production of Crops: Barley. Retrieved from http://faostat3.fao.org/browse/Q/QC/E.

Fiala, M., Nonini, L., & Marveggio, D. (2019). Environmental assessment. Task 4.3 final report, project *"BARPLUS–Modifying canopy architecture and photosynthesis to maximize barley biomass and yield for different end-uses"*, (Internal FACCE-SURPLUS ERA-NET Project report, June 2019) (pp. 122).

Jannick, H. S., Weidema, B. P., Munõz, I., Dalgaard, R., Merciai, S., & de Saxcé, M. (2010). 2.0 LCA Consultants. www.lca-net.com.

Keyes, S., Tyedmers, P., & Beazley, K. (2015). Evaluating the environmental impacts of conventional and organic apple production in Nova Scotia, Canada, through life cycle assessment. *Journal of Cleaner Production, 104,* 40–51.

Lovarelli, D., Bacenetti, J., & Fiala, M. (2016). A new tool for life cycle inventories of agricultural machinery operations. *Journal of Agricultural Engineering, 47*(1), 40–53.

Lovarelli, D., Bacenetti, J., & Fiala, M. (2017). Effect of local conditions and machinery characteristics on the environmental impacts of primary soil tillage. *Journal of Cleaner Production, 140,* 479–491.

Lovarelli, D., Fiala, M., & Larson, G. (2018). Fuel consumption and exhaust emissions during on-field tractor activity: A possible improving strategy for the environmental load of agricultural mechanisation. *Computers and Electronics in Agriculture, 151,* 238–248.

Marinussen, M., van Kernebeek, H., Broekema, R., Groen, E., Kool, A., van Zeist, W. J., et al. (2012). LCI data for the calculation tool feedprint for greenhouse gas emissions of feed production and utilization. http://www.blonkconsultants.nl/wpcontent/uploads/2016/06/Cultitvation-cereals-D03.pdf.

Murphy, C. W., & Kendall, A. (2013). Life cycle inventory development for corn and stover production systems under different allocation methods. *Biomass and Bioenergy, 58,* 67–75.

Nemecek, T., & Kägi, T. (2007). Life cycle inventories of Swiss and European agricultural production systems. Final report ecoinvent V2.0 No. 15a, Agroscope Reckenholz-Taenikon Research Station ART, Swiss Centre for Life Cycle Inventories, Zurich and Dübendorf, CH. Retrieved from www.ecoinvent.ch.

Niero, M., Ingvordsen, C. H., Peltonen-Sainio, P., Jalli, M., Lyngkjær, M. F., Hauschild, M. Z., et al. (2015). Eco-efficient production of spring barley in a changed climate: a life cycle assessment including primary data from future climate scenarios. *Agricultural Systems, 136,* 46–60.

Notarnicola, B., Sala, S., Anton, A., McLaren, S. J., Saouter, E., & Sonesson, U. (2017). The role of life cycle assessment in supporting sustainable agri-food systems: a review of the challenges. *Journal of Cleaner Production, 140,* 399–409.

Ossés de Eicker, M., Hischier, R., Kulay, L. A., Lehmann, M., Zah, R., & Hurni, H. (2010). The applicability of non-local LCI data for LCA. *Environmental Impact Assessment Review, 30*(3), 192–199.

Reboul, C. (1964). Temps des travaux et jours disponibles en agriculture. *Economie Rurale, 61,* 50–80.

Schmidt Rivera, X. C., Bacenetti, J., Fusi, A., & Niero, M. (2017). The influence of fertiliser and pesticide emissions model on life cycle assessment of agricultural products: The case of Danish and Italian barley. *Science of Total Environment, 592,* 745–757.

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