ENVIRONMENTAL IMPACT ASSESSMENT OF FIBER SORGHUM (SUDAN-GRASS) PRODUCTION SYSTEMS FOR BIOMASS ENERGY PRODUCTION IN A CENTRAL REGION OF ITALY

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ABSTRACT: The environmental performance of fiber sorghum crop production systems in Umbria (Italy) was analyzed using a LCA methodology, tailored to biomass production. Two different tillage systems were compared concerning the type of irrigation: dryland conditions and traveling big-gun system. The analysis considered the entire system, which was required to produce 1 MJ of fiber sorghum energy content; it included the extraction of raw materials, like fossil fuels and minerals, the production of farming inputs, such as fertilizers and pesticides, and all agricultural operations in the field. Information about resource consumption associated to crops production was taken from a field trial in Italy (Casalina, Perugia). The LCA method used in this study aggregates all resources used and all emissions released into environment, defined into Life Cycle Inventory, in the following impact categories: depletion of abiotic resources, freshwater consumption, climate change, land use, acidification, eutrophication, human toxicity, eco-toxicity, soil erosion. Results reveals that dryland and irrigated conditions are characterized by an equivalent environmental impact mostly due to phosphate fertilizers consumption, soil erosion, nitrate emissions and, for irrigated conditions, water consumption. Tested method seemed suitable to evaluate environmental burdens of energy crops, because it only considers impact categories important for biomass production.
KEYWORDS: Life Cycle Assessment (LCA), sorghum, Global Eco-Index.

1 INTRODUCTION

This study examines the environmental impact, through Life Cycle Assessment methodology, of fiber sorghum (variety H952) production, adopting two different agricultural techniques mainly regarding irrigation management. Life Cycle Assessment (LCA) is an appropriate methodology to investigate the environmental impact of products, because it takes into account all relevant impacts occurring during the entire production system.

In the present paper a LCA method that integrates the relevant environmental effects to crop production was adopted. The method, in compliance with ISO 14040 series, divides a LCA study in the following steps: definition of goal and scope, inventory analysis, impact assessment and interpretation. Regarding the first step, the aim of the work was the environmental impact, on a life cycle horizon, of fiber sorghum cultivation for biomass production. The fiber sorghum agricultural production models field data were collected during the establishment of 4,08 ha in Casalina in 2006. In particular 1,4 ha were dedicated to dryland conditions and 1,34 ha to traveling big-gun irrigation system. The trial fields were provided with necessary instrumentation to realize a climate monitoring and a control of physiological parameters, chemical-physical properties of plants and soil characteristics.

2 INVENTORY ANALYSIS

The inventory analysis is the quantitative description of all material and energy flows across the system boundary either into or out of the system itself. The reference functional unit for the inventory analysis and impact assessment is 1 MJ of fiber sorghum energy content, measured in terms of the lower heating value. All the energy and mass flows in the inventory are normalized to this functional unit. Field operation input data are reported in table 1. Data, relative to time of agricultural operations and materials consumption, were drawn from field workbook, while fuel and lubricant oil consumption for agricultural machines were estimated applying the methodology reported in [1]. Machineries (tractors and agricultural machineries) and infrastructures (irrigation system) used in the processes were not considered throughout the study. For the cultivation of fiber sorghum with traveling big-gun irrigation system, it was assumed an amount of water sprayed on the field of 1600 m^3/ha. It was distributed on four irrigation units and the water was taken from surface water using a pump equipped with a 22 kW engine, with a volumetric capacity of 30 m^3/h. Therefore it was considered an electricity consumption of 876 kWh/ha for the water pump. For human labour was registered a total consumption of 12,9 h/ha (in dryland conditions) and 14 h/ha (in irrigated conditions).

Moreover in the inventory analysis were considered the following data from the experimental fields in Casalina:

- air emissions produced by diesel engines, calculated using the method reported in [1];
- air emissions of ammonia (17,2 kg/ha in dryland conditions and 24,1 kg/ha in irrigated conditions) and dinitrogen monoxide (1,2 kg/ha in dryland conditions and 1,7 kg/ha in irrigated conditions) from the application of fertilizers, using the method described in [2];
- emissions to the water of phosphates through run-off (0,2 kg/ha in dryland and irrigated conditions) and nitrates through leaching (20,8 kg/ha in dryland conditions and 24,7 kg/ha in irrigated conditions) due to the application of fertilizers, employing the procedure reported in [1] and in [2] respectively;
- air emissions of VOC (0,42 kg/ha in both conditions) and pesticides (0,17 kg/ha of simazine in both conditions) from the application of pesticides, calculated using the method reported in [3];
- soil pollution (0,39 kg/ha of simazine in both conditions), deriving from the remained of pesticides in the soil, calculated using the method reported in [3], and from cadmium soil accumulation (4,23 g/ha) due to mineral phosphate fertilizer application.

In particular it was assumed that a fraction of airborne NO_x and NH_3 emissions reaches marine ecosystems; in Italy these factors are equal to 0,19 for NO_x and 0,21 for NH_3 [4].

In the following, the parameters necessary to calculate the emissions are reported:

- biological N fixation: none;
- atmospheric N deposition: 7,5 kgN/(ha*yr);
- N net-mineralization: 35 kgN/ha [5];
- N removal with harvested crops: 2,5 kgN/ton of biomass [6];
- soil texture: sandy-clay;
- average precipitation per year: 602,4 mm (331,6 mm in summer and 270,8 in winter). In irrigated conditions, water was considered increasing rainfall in summer, so in this conditions the average precipitation per year was 762,4 mm. However, in both conditions the exchange frequency of the drainage water per year was higher than 1, so the whole amount of nitrate was supposed to be leached;
- biomass production (moisture 65%, LHV wet basis 16,9 MJ/kg): 63,3 ton/ha (dryland conditions), 83,1 ton/ha (irrigated conditions);
- quantity of P_2O_5 contained in mineral fertilizers: 70,5 kg/ha;
- formulation of pesticide: wettable powder, containing 42,8% of active ingredient.

3 LIFE CYCLE IMPACT ASSESSMENT

3.1 Characterization

In the present study the following impact categories were considered: depletion of abiotic resources, freshwater consumption, climate change, land use, acidification, eutrophication, human toxicity, eco-toxicity and soil erosion. Then, the indicator result for each impact category was determined, multiplying the aggregated resources used and the aggregated emissions of each individual substance for a characterization factor for each impact category to which it may potentially contribute. Characterization factors (FC) are substance-specific, quantitative representations of the additional environmental pressure per unit emission of a substance.

<u>Depletion of abiotic resources</u>

In this impact category, resources which are functionally equivalent to each other, are aggregated into sub-categories. In a LCA study of energetic crops the principal sub-categories are depletion of fossil fuels (expressed in MJ), phosphate rock (in kg P_2O_5), potash (in kg K_2O) and human labour (in MJ). Table 2 shows the characterization factors [4] for abiotic resources typically consumed in an agricultural system.

The characterization factor of the human labour resource was calculated beginning from an analysis of energetic metabolism of Italian society. In 1999 57,7 million Italians represented an amount of 503,7 Giga-hours of human activities and consumed 7 Exa-Joules of primary energy [7]. So Italy has a per capita energy consumption of 14 MJ/hour, that it could be assumed as the characterization factor.

Table 1. Field operations data for cultivation in dryland conditions (D) and with traveling big-gun irrigation system (I).

Operation	**Machinery**	**Operating rate (h/ha)**		**Diesel consumption (kg/ha)**		**Lubricant oil consumption (kg/ha)**		**Material**	
		D	**I**	**D**	**I**	**D**	**I**	**D**	**I**
Ploughing	tractor (157 kW) + ploughshare	1,43	1,49	46,40	48,47	3,48	3,48		
Extirpating	tractor (157 kW) + weeder	0,49	0,57	15,84	18,56	3,48	3,48		
Surface dressing	tractor (60 kW) + fertilizer spread	0,39	0,37	4,85	4,62	1,35	1,35	triple perpho. (47%P_2O_5) 150 kg/ha	150 kg/ha
First harrowing	tractor (93 kW) + spring tine harrow	0,71	0,82	13,81	15,85	2,09	2,09		
Second harrowing	tractor (179 kW) + rotary harrow	0,69	0,78	25,60	29,00	3,98	3,98		
Sowing	tractor (60 kW) + sower	1,33	1,33	16,50	16,50	1,35	1,35		
Weed control	tractor (60 kW) + field sprayer	0,18	0,19	2,21	2,31	1,35	1,35	simazine 1,3 kg/ha	1,3 kg/ha
Field dressing	tractor (60 kW) + fertilizer spread	0,29	0,34	3,54	4,15	1,35	1,35	urea (46%N_2) 250 kg/ha	350 kg/ha
Hoeing	tractor (60 kW) + weeder	0,71	0,66	8,84	8,14	1,35	1,35		
Cutting	Combine harvester (202 kW)	0,23	0,23	9,57	9,57	4,48	4,48		
First turning	tractor (52 kW) + tedder	0,79	0,79	8,52	8,52	1,19	1,19		
Second turning	tractor (52 kW) + tedder	0,79	0,79	8,52	8,52	1,19	1,19		
Windrowing	tractor (60 kW) + rotary rake	0,48	0,48	5,89	5,89	1,35	1,35		
Harvesting and pressing	tractor (82 kW) + round baler	1,82	1,82	30,93	30,93	1,85	1,85		

Table 2. Characterization factors (FC) for abiotic resources.

Sub-categories	Resource	Unit	FC
Depletion of fossil fuels (in MJ)	Diesel oil	kg	42,868
	Natural gas	m^3	31,736
Depletion of phosphate rock (in kg P_2O_5)	Phosphate rock	kg	0,25
	Raw phosphate	kg	0,32
Depletion of human labour (in MJ)	Human labour	hours	14

Freshwater consumption

This impact category relates the use of water to the freshwater resources, including surface and groundwater. Abstraction rates must be sustainable in order to ensure the protection and management of water resources and related ecosystems. The characterization factor is simply represented by m^3 of water used for irrigation.

Land use

This impact category describes the environmental impact resulting from land use for human activities. In particular, the land use category considers natural land as a resource and assumes that land occupation and management causes consumption of the resource. Natural land can be defined as the addition of land not damaged at the moment by human activities and the remaining natural land fraction under use.

To determine this fraction, it can be applied Hemeroby concept [8] that measures human influence on ecosystems and it is used to characterize the environmental impact of different types of land use. The level of Hemeroby depends on the degree of human impacts, that prevent the system from developing towards a natural endpoint situation. This natural endpoint situation describes the reference to which any modified situation is compared. Therefore the land area used for a certain period of time (in m^2 per year) was multiplied for the characterization factor, called *naturalness degradation potentials*, for intensive arable land use, assumed equal to 0,8 [8].

Climate change

Climate change is caused by the release of *greenhouse gases* such as carbon dioxide (CO_2). The characterization model is based on factors developed by the UN Intergovernmental Panel on Climate Change (IPCC); factors are expressed as Global Warming Potential (GWP) over the time horizon of 100 years (GWP100), measured in the reference unit, kg of equivalent CO_2.

Human toxicity

For human toxicity impact category, the concept of disability-adjusted life years (DALY) is used. In this model weights for the different severity of human health effects were established; they allowed comparisons between time lived with a certain limitation and time lost due to premature mortality. The human toxicity potential (HTP) for emissions of toxic substances is expressed in DALY and the relative characterization factors are reported in [9].

Eco-toxicity

The emission of some substances can have impacts on ecosystems. Ecotoxicity Potentials (ETP) are calculated with the USES-LCA, which is based on EUSES, the EU's toxicity model. This provides a method for describing fate, exposure and the effects of toxic substances on the environment. Characterization factors [10] are expressed using the reference unit, kg 1,4-dichlorobenzene equivalents (1,4-DB)/kg emission, and are measured separately for impacts of toxic substances on fresh-water aquatic ecosystems, terrestrial ecosystems, marine aquatic ecosystems, marine sediment ecosystems and fresh water sediment ecosystems.

Acidification

Acid gases react with water in the atmosphere to form *acid rain*, which can cause ecosystem impairment. Therefore the principal emissions that cause acidification impacts are sulfur dioxide (SO_2), nitrogen oxides (NO_x) and ammonia (NH_3). In particular, the application of mineral fertilizers can cause high emissions of NH_3, due to volatilization during and after application of urea.

Acidification potential of emissions depends on the deposition forms and the different sensitivity of the receiving area. The method developed by Huijbregts (RAINS-LCA) includes this kind of information and supplies characterization factors (for SO_2, NO_x, NH_3) specific for European countries, expressed in SO_2 eq. For Italy the following values were assumed: 0,59 kg SO_2 eq./kg NH_3, 0,13 kg SO_2 eq./kg NO_x, 0,46 kg SO_2 eq./kg SO_2 [10].

Terrestrial eutrophication

Huijbregts [10] developed a characterization method of terrestrial eutrophication that considers atmospheric pathways, deposition patterns and eutrophication effects of NO_x and NH_3 emissions. Since nitrogen is the most important limiting factor for terrestrial ecosystems, NO_x and NH_3 depositions represent the principal contributions to the terrestrial eutrophication. This method supplies terrestrial eutrophication potentials (TEP) specific for European countries, expressed in NO_x equivalents. For Italy the following values were assumed: 0,60 kg NO_x eq./kg NO_x, 2,80 kg NO_x eq./kg NH_3.

Aquatic eutrophication

Nitrates and phosphates are essential for life, but increased concentrations in water can encourage excessive growth of algae, reducing the oxygen within the water and damaging ecosystems. The anthropogenic emissions of nitrates and phosphates, considered in this paper, are depositions of airborne NO_x and NH_3 on surface waters and diffuse losses of nitrate and phosphate via leaching. The characterization factors [4], expressed in kg PO_4 equivalents per kg emission, are 0,35 (NH_3), 0,13 (NO_x), 0,10 (NO_3) and 1,00 (PO_4).

Soil erosion

Soil erosion is a serious kind of degradation since it is irreversible. The soil loss also means a loss of plant nutrients and organic matter which can impair the land's productivity. The characterization factor was calculated applying the Universal Soil Loss Equation (USLE). The USLE is an empirical equation that computes the mean annual soil loss by multiplying 5 factors.

$$FC = R * K * LS * C * P \qquad (1)$$

where:

R = rainfall erosivity factor (144,4 MJ mm ha^{-1} h^{-1} yr^{-1} in dryland conditions and 211 MJ mm ha^{-1} h^{-1} yr^{-1} in irrigated conditions);

K = soil erodibility factor (0,13 t h $MJ^{-1}mm^{-1}$);

LS = slope length-gradient factor (0,8);

C = crop/vegetation and management factor (0,15, it was assumed *cereal*s as land cover type from October to May and *grassland* from June to September);

P = practice factor (1).

In dryland conditions it was obtained a characterization factor of 2,25 $t*ha^{-1}*yr^{-1}$, while in irrigated conditions a value of 3,3 $t*ha^{-1}*yr^{-1}$, assuming a slope of 2% and a length of 200 m of land.

3.2 Normalization

Normalization is used to express impact indicator data in a way that allows a comparison among impact categories. This procedure normalizes the indicator results, obtained in the characterization step, by dividing by a selected reference value. The decision about which reference situation shall be used depends on the subsequent weighting procedure, as well as on the availability of normalization data.

Depletion of abiotic resources

It was considered the yearly consumption per person in Europe for the sub-categories of depletion of fossil fuels and depletion of phosphate rock [4]. As regards the depletion of human labour, it was considered the yearly consumption of primary energy per person in Italy for activities accomplishment. Table 3 shows the normalization values (NV).

Table 3. Normalization values for depletion of abiotic resources.

Sub-categories	Total consumption	NV
Depletion of fossil fuels (in MJ per person)	$9{,}69*10^{13}$	$1{,}33*10^{5}$
Depletion of phosphate rock (in kg P_2O_5 per person)	$5{,}57*10^{9}$	7,66
Depletion of human labour (in MJ per person)	$7{,}00*10^{18}$	$1{,}21*10^{5}$

Freshwater consumption

Normalization value for freshwater consumption is represented by the mean annual total abstractions of freshwater per person in Italy

$$NV_{freshwater\ consumption} = AF/P_{Italy} = 9{,}74*10^2\ m^3 \text{ per person} \quad (2)$$

where:
AF = current annual total abstractions of freshwater (56.200 Mm^3 [11]);
P_{Italy} = population of Italy in 2003 (57.700.000 inhabitants).

Land use

The impact assessment of land use has to be related specifically to ecologically homogenous land units [12]. Therefore Europe was divided into 11 biogeographic regions, in order to reflect roughly the pattern of environmental conditions. To determine normalization values it is necessary to calculate the parameter NDI_{region}, that represents naturalness degradation indicator for the land (for Mediterranean region it ia equal to $1{,}17 \times 10^{13}$ m^2*year [12]). Then, to make the normalization results of land use comparable to the results of other impacts, a more common reference region like total Europe, rather than a single biogeographic region, has to be selected.

So normalization values for land use impact are obtained according to the following equation:

$$NV_{land\ use} = [(A_{Europe}/A_{bioreg})*NDI_{region}]/P \quad (3)$$

where:
A_{Europe} = total area of Europe;
A_{bioreg} = total area of biogeographic region of land;
P = population of Europe (727.000.000 inhabitants).

Being the field trial in Mediterranean region, the relative normalization value is $1{,}61 \times 10^4$ ha*year per person [12].

Climate change

Normalization value for climate change impact category was determined by the following equation:

$$NV_{climate\ change} = CO_{2,\ tot}/P_{Italy} = 9{,}88 * 10^3 \text{ kg } CO_2\text{-eq. per person} \quad (4)$$

where:
$CO_{2,\ tot}$ = total greenhouse gas emissions in Italy in 2003 (569.828.000 ton of CO_2 equivalents) [13];
P_{Italy} = population of Italy in 2003 (57.700.000 inhabitants).

Human toxicity

Normalization value was obtained according to EcoIndicator impact assessment method. The impact of each pollutant of this category, expressed in DALY/kg, was multiplied for the yearly amount emitted in Europe (in all environmental compartments). Then these values were summed and divided for European population, obtaining a normalization value equal to $7{,}5*10^{-3}$ DALY per person [4].

Eco-toxicity

For the eco-toxicity impact categories it was proceeded in the same way as for human toxicity impact category. The normalization values [4], expressed in kg 1,4-DCB-eq. per person, are: $1{,}15*10^2$ (terrestrial ecosystems), $1{,}24*10^3$ (fresh-water aquatic ecosystems), $2{,}88*10^5$ (marine aquatic ecosystems), $1{,}28*10^3$ (fresh water sediment ecosystems), $2{,}65*10^5$ (marine sediment ecosystems).

Acidification

Normalization value for acidification impact category was determined by the follow equation.

$$NV_{acidification} = SO_{2,\,tot}\,eq./P_{Italy} = 11{,}9 \text{ kg } SO_2\text{-eq. per person} \quad (5)$$

where:

$SO_{2,\,tot}$ eq. = total SO_2 equiv. emissions in Italy in 2003 (688.040.000 kg), obtained multiplying total Italian emissions of NH_3 (448 kton), NO_x (1200 kton) and SO_2 (582 kton) for the relative characterization factors [13];

P_{Italy} = population of Italy in 2003 (57.700.000 inhabitants).

Terrestrial eutrophication

Normalization value for terrestrial eutrophication impact category was determined by the following equation:

$$NV_{terrestrial\ eutrophication} = NO_{x,\,tot}\,eq./P_{Italy} = 34{,}2 \text{ kg } NO_x\text{-eq. per person} \quad (6)$$

where:

$NO_{x,\,tot}$ eq. = total NO_x equiv. emissions in Italy in 2003 (1.974.400.000 kg), obtained multiplying total Italian emissions of NH_3 (448 kton) and NO_x (1200 kton) for the relative characterization factors [13];

P_{Italy} = population of Italy in 2003 (57.700.000 inhabitants).

Aquatic eutrophication

It was assumed the score (relative to European territory) reported in [10], because of the lack of more recent data. Then this value was divided for the European population, obtaining a normalization value equal to 8,56 kg PO_4-eq per person.

Soil erosion

According to [14], about 115 million hectares (12% of the total European land area) are suffering from water erosion and the average soil erosion rate in Europe is 17 ton per hectare per year.

Therefore the yearly eroded soil in Europe is 1.955.000.000 ton, which divided for the European population provides the normalization value for soil erosion impact category (2,69 ton per person).

3.3 Weighting

Weighting means to evaluate different environmental effects according to their severity and to aggregate the weighted impact indicator values across all impact categories to one overall environmental indicator. In this study, the weighting of the normalized impact indicator values was performed according to the distance to target principle that means a comparison of the current level of an environmental effect in a certain region and time to a target level of the same effect.

Depletion of abiotic resources

Based on data on the estimated global recoverable reserves of a resource, it was calculated which theoretical annual extraction would be tolerable in order to ensure an availability of the respective resources for 100 years. Then the quotient of the current annual production and the previous score gives the weighting factors (WF) for the depletion of fossil fuels (1,05) and phosphate rock (1,20) [4]. As regards the human labour sub-category, it was assumed that the reference scenario coincides with the actual and so the weighting factor for human labour was considered equal to 1.

Freshwater consumption

In [11] is defined the water exploitation index as the mean annual total abstractions of freshwater divided by the mean annual freshwater resources, which are derived from the mean annual precipitation minus the mean annual evapotranspiration plus the mean annual inflows in each country. Actually in Italy this index is 32,1%, but the warning threshold can be 20 %, which distinguishes a non-stressed region from a stressed region. Therefore the weighting factor (1,61) was determined by the following equation:

$$WF_{freshwater\ consumption} = AF/(0{,}2*FR) \quad (7)$$

where:

AF = current annual total abstractions of freshwater (56.200 Mm^3);

FR = annual freshwater resources (175.000 Mm^3).

Land use

Weighting of the land use impact category requires to find targets on a tolerable anthropogenic utilization of land in Europe, but actually these targets are not available. Therefore it was considered that the current situation is equivalent to the target scenario and the relative weighting factor is 1 for every biogeographic region.

Climate change

For this impact category the weighting factor was derived by using authorized environmental goal like the Kyoto protocol [15]. In Italy CO_2 eq. emissions were $5{,}54*10^8$ ton in 2002, while the goal is to reduce by 6,5% these emissions compared with year 1990 ($4{,}75*10^8$ ton), during 2008-2012. Therefore the weighting factor is 1,17.

Human toxicity

This impact category includes carcinogenic emissions and those that can give rise to respiratory diseases. Therefore it was considered death and disability adjusted life years (DALY) estimated for 2002 in Europe (24.180.608 DALY) because of cancer and respiratory disease onsets. As target value it was assumed DALY assessment for 2030 (20.517.225 DALY), so the relative weighting factor is 1,18 [16].

Eco-toxicity

As for the land use impact category, at this moment specific targets for the reduction of toxic emissions are not defined. Therefore it was assumed a weighting factor equal to 1 for all ecosystems.

Acidification

In Directive 2001/81/EC [17] are reported the Italian emission ceilings for NH_3 (419 kton), NO_x (990 kton) and SO_2 (475 kton) to be attained by 2010. So the corresponding acidification potential is 584,4 kton kg SO_2 eq. and the weighting factor is 1,18, obtained dividing total SO_2 equivalents emissions in Italy in 2003 (688.040.000 kg) for the aforesaid score.

Terrestrial eutrophication

Considering the ceilings defined in Directive 2001/81/EC [17] for NH_3 and NO_x, the corresponding terrestrial eutrophication potential is 1767,2 kton and the weighting factor is 1,12, obtained dividing total NO_x equivalents emissions in Italy in 2003 (1.974.400.000 kg) for the aforesaid score.

Aquatic eutrophication

As weighting factor it was assumed the value reported in [4], that is 1,37, based on emission rates and reduction targets for Western European signatory states of OSPAR and HELCOM conventions.

Soil erosion

Theoretical target value, for this impact category, would have to coincide with the average rate of soil formation (about 1 ton per hectare per year). As soil loss occurs at higher rates than formation across most parts of Europe, it is more realistic to consider soil loss as tolerable if no significant decline of soil fertility may be expected within a period of 300 to 500 years. Tolerable soil loss was determined adopting the procedure reported in [18]; in particular for the field site examined (Casalina), the following parameters to determine soil depth were assumed:

- depth class of an obstacle to roots: no obstacle to roots between 0 and 80 cm;
- presence of an impermeable layer within the soil profile: no impermeable layer within 150 cm;
- depth to rock: 80 – 120 cm.

From these assumptions, it was obtained a soil depth of 100 cm, a tolerable soil loss of 7 ton/ha/year and a weighting factor of 2,43.

4 RESULTS AND CONCLUSIONS

Figure 1 shows the global eco-index, expressed in micro-Points (μPt), for each impact category and for the two different tillage systems.

Impact categories	D	I
Depletion of fossil fuels	0,511	0,432
Freshwater consumption	0,066	5,323
Land use	1,311	0,994
Climate change	0,114	0,123
Human toxicity	0,883	0,780
FAETP	2,685	2,040
MAETP	0,006	0,005
FSETP	2,289	1,750
MSETP	0,009	0,007
TETP	0,316	0,241
Acidification	3,074	3,064
Terrestrial eutrophication	3,701	3,864
Aquatic eutrophication	4,097	3,409
Soil erosion	6,558	5,979
Depletion of phosphate rock	7,379	5,624
Depletion of human labour	0,006	0,004
Total	*33,003*	*33,639*

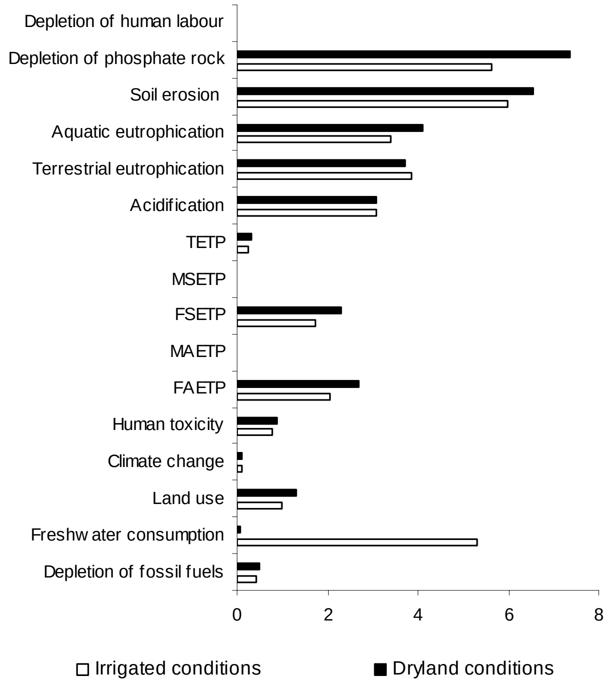

Figure 1. Global Eco-Index values (in µPt/MJ), evaluated with the new methodology.

It can be noted that the difference between the two tillage systems is very low, about 2%, so these agricultural techniques can be considered equivalent from the point of view of environmental impact, thanks to the higher biomass production of irrigated conditions. It is due to the fact that summer 2006 was a very raining season (about 20 mm in August and 50 mm in September more than the mean values for Perugia). Results stress that the impact of arable farming on decreasing availability of exploitable phosphate rock resources is by far greater than that on decreasing availability of fossil fuel resources. Since phosphate rock reserves are scarce and phosphates are essential nutrients in crop production, a sustainable use of P resources is important. Other categories, characterized by an high value of global eco-index, are soil erosion and eutrophication (aquatic and terrestrial), which could be reduced adopting soil conservation measures, applying nitrogen according to crop demand in order to minimize NO_3 leaching and using nitrogen fertilizers with low NH_3 volatilization rates.

Besides it seemed interesting to evaluate the environmental impact of the two tillage systems with other impact assessment methods not tailored to biomass production but primarily designed for industrial applications, like EcoIndicator 99 and EPS 2000, that include the weighting step. Results (Table 4) revealed that in both cases the environmental burden (about 85-90% due to the land use category in EcoIndicator 99 method and depletion of reserves category in EPS 2000 method) of irrigated conditions is lower than dryland conditions unlike the outcomes obtained using our method. This fact can be explained because in these approaches, some important environmental impacts are not included (e.g. freshwater consumption, nutrient emissions into water in EcoIndicator 99, soil erosion in EcoIndicator 99 and EPS 2000); furthermore EPS 2000 is not transparent in its monetary weighting procedure and, like EcoIndicator 99, cannot be performed site-specific. Table 4 reports also the environmental impact of the two tillage systems using our model but assuming that biomass productivity, with the same agricultural inputs, was equal to Literature data [19] (20 ton dry matter/ha in dryland conditions and 35 ton dry matter/ha in irrigated conditions). In EcoIndicator 99 dryland and irrigated conditions differ for 8,1%, in EPS 2000 for 13,9% while with our methodology values differ for 26,9%; it confirms a more detailed approach of the last one to the cultivation phase of the bioenergy chain.

Table 4. Environmental impact obtained with EcoIndicator 99, EPS 2000 and our model (in µPt/MJ).

	EcoIndicator 99	**EPS 2000**	**Our model** (Literature data)
Dryland conditions	2730	2590	37,096
Irrigated conditions	2510	2230	27,127

According the results obtained, the life cycle impact assessment illustrated in this paper is seemed interesting to compare and evaluate the environmental impact of cultivation systems for biomass production, because permits to calculate a sustainability indicator that includes the most important impact categories for intensive farming. The method will have to be improved, defining normalization and weighting factors referred to the same Region and including more economic and social aspects such as employment, rural development or cost-benefit analysis.

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