Annals of Silvicultural Research
45(1), 2020: 76-82
https://journals-crea.4science.it/index.php/asr

Research paper

Collection: "4th Italian National Congress of Silviculture"
Torino, 5-9 November 2018

Life Cycle Assessment (LCA): new poplar clones allow an environmentally sustainable cultivation

Pier Mario Chiarabaglio[1], Andrea Deidda[2], Sara Bergante[1*], Gaetano Castro[1], Gianni Facciotto[1], Achille Giorcelli[1], Simonetta Pagliolico[3], Corrado Carbonaro[2]

Received: 31/01/2019 Accepted: 7/11/2019 Published: 24/08/20

ABSTRACT In Italy 72 poplar clones *(Populus* spp.*)* are registered for commercialization. They were selected for fast growth, stem shape and disease resistance. The new selections (named MSA) includes genotypes with very high resistance to all the main diseases and to one insect, *Phloeomizus passerinii* (Sign.). Fast growth and disease resistance allow to produce wood with low environmental and economic costs; for this reason in some Italian Regions the introduction of a percentage of these clones in poplar stand is mandatory to obtain funding for their establishment (Rural Development Plan). To better understand the environmental advantages deriving from the use of these clones, in comparison with the old genotypes (particularly 'I-214'), a 'Life Cycle Assessment' approach was applied considering as impact indicator the CO_2 equivalent emissions; from stoolbed to commercial stand, primary data were collected from an Italian experience. Firstly with the Inventory Analysis all the raw material, energy, wastes and emissions related were collected for each cultivation phase. The analysis showed a reduction of 9% of CO_2 eq. ha^{-1} emitted, growing MSA instead of 'I-214'. Considering the emissions per volume of wood, 'I-214' requests 47.5 kg CO_2 eq. per m^3, compared with MSA that request 36.6 kg CO_2 eq. per m^3.

KEYWORDS: Life Cycle Assessment, poplar, sustainability.

Introduction

In Italy the selection of new poplar clones, carried out by both public research bodies and private ones, allowed to select and to register for commercialization 72 poplar clones (*Populus* spp.) from the 1940s to today. The selection activity started early to find new genotypes resistant to *Venturia populina* (Vuill.) Fabric., a fungi disease that causes the desiccation and fall of leaves and shoots in Spring (Cellerino and Anselmi 1980, Cellerino and Anselmi 1982a); the first group of clones selected, contained the clone 'I-214' (a *Populus ×canadensis* genotype), currently the most widespread and required clone by industry, in Italy and Europe.

The main characteristics selected through controlled breeding and *in situ* free pollination are fast and constant growth, apical dominance, straight and cylindrical stem, limited and ordered branching and disease resistance. Poplar is susceptible to many fungal pathogens and is attacked by phytophagous insects; different diseases have alternated over the years, and with worldwide trades and climate change, new problems periodically affect the plantations. For example, in the 1960s, the advent of *Marssonina brunnea* (Ell. et Ev.) P. Magn. on cultivations caused many problems and a consequent increase in the use of chemicals for disease control (Cellerino and Anselmi 1982b).

Over the years, the selection program has adapted to the new needs, while maintaining the characteristics of resistance of the clones of the previous selections. The continuous introduction of new races and ecotypes of fungal diseases, their rapid adaptation and the relative long selection times of the poplar make the improvement activity quite difficult.

Nevertheless, the last new series of poplar clones includes genotypes with very high resistance to all the main poplar diseases (7 different fungi) and to one insect, *Phloeomizus passerinii* (Sign.), which still creates many problems in plantations realized with the clone 'I-214'. They also show a growth greater than 'I-214'. Fast growth and disease resistance allow to produce wood with low environmental and economic costs, because less chemicals are required for cultivations and with the same time of soil occupation it's possible to reach higher yields; for these reasons the new clones are called 'MSA', the acronym for Italian 'Maggior Sostenibilità Ambientale', that means 'greater environmental sustainability' and in some Italian administrative Regions, introducing in new plantations a percentage of trees of these clones is mandatory to obtain funding for the establishment within the Rural Development Plan. With the sensible reduction of chemicals the environmental and economic advantages are clear, but to better understand the real impact of this innovations a 'Life Cycle Oriented' analysis was applied. The environmental hotspots (i.e. processes mainly responsible for the environmental impact) were identified and two scenarios involving the cultivation of MSA clones compared with traditional clones that needs chemicals controls were considered.

1 CREA – Research Centre for Forestry and Wood – Italy
2 Department of Architecture and Design, Politecnico di Torino – Italy
3 Department of Applied Science and Technology, Politecnico di Torino - Italy
*Corresponding author: sara.bergante@crea.gov.it

http://dx.doi.org/10.12899/asr-2017

The cultivation of MSA clones was compared with traditional cultivation of 'I-214' from nursery phase to mature trees harvest, using primary data of 15 years of growth, obtained in experimental stands in Italy.

Life Cycle Assessment (LCA) is a holistic methodology that aims to analyze products, processes, or services from an environmental perspective (ISO 14040, 2006). Although originally developed for industrial processes, in the past few decades, it has increasingly become employed to analyze agricultural systems (Bacenetti et al. 2016).

The work focused firstly on the realization of an Life Cycle Inventory Analysis (LCI ISO 14041:1999) in which, for each cultivation phase, all the raw material, energy and emissions related to cultural inputs were identified and evaluated. There are few LCA analyses available in literature based on primary inventory data of the cultivation process (Krzyzaniak, et al. 2019 ; Lovarelli et al. 2018). Generally, secondary datasets are used, obtained from databases such as Ecoinvent v3.0. In order to ensure reliable construction the LCA of primary cultivation data is necessary. Our experimental study is based on quantified values originating from field trial, or originating from a calculation based on direct measurements, and it may contribute to fill the gap in literature. The LCI analysis is propaedeutic to the successive Analysis of Impacts (LCIA, ISO 14042:2000) which will be developed in a future work. First results concerning the carbon footprint of the poplar cultivation are illustrated in this paper, as the global warming and the climate changes are currently considered the most popular environmental issues of concern. The possibility to quantify environmental sustainability, especially in the field of CO_2 equivalent emissions, represent a strong instrument to understand and to weigh the advantages linked to the choice of one or the other cultivation model also in view of a possible remuneration for environmental services.

Materials and methods

LCA methodology

The Life Cycle Assessment (LCA) was performed according to ISO 14040 series recommendations. The calculation software SimaPro 8.0 was used for modelling the poplar production cycle in order to analyze the environmental impact. The main database used for input data was Ecoinvent v3.0. In support of Ecoinvent v3.0, other database have been identified such us Agrifootprint, ELCD, USLCI 1.60, AusLCI. The IPCC 100 (kgCO_2eq) is the method applied for impact calculation because the Carbon sequestration in Italy is currently the only one ecosystem service for which a voluntary market is possible. Other indicators will be showed in a future paper where the entire production cycle will be analyzed up to the plywood panel production.

Goal and scope definition

The goal of this study is to assess the environmental impact of poplar cultivation for raw material production for industry, demonstrating, in our case that the cultivation of new clones resistant to main poplar disease, considering processes and tools used, is actually more sustainable than a cultivation with 'I-214', a traditional clone that need high cultural inputs.

In more detail, the research questions can be summarized as follows:

(i) What is the environmental impact of poplar cultivation performed with different poplar clones?

(ii) What are the main environmental hotspots associated with the cultivation?

(iii) Between the traditional and new MSA clones, which solution has the lower environmental impact?

The study outcomes can be useful for farmers and for stakeholders involved in the poplar cultivation and wood market and for local politicians involved in the decisional processes.

System description and boundary

The cultivations analysed for data extraction are in Piedmont, along the Po Valley, in the 'Mezzi' farm of CREA- Research Centre for Forestry and Wood, Casale Monferrato, Italy. The farm covers a surface of about 180 ha in the flooding area of Po river; the environment is quite representative of the suitable conditions for poplar cultivation: the average annual temperature is around 13 °C; the annual total rain is between 700 and 800 mm with about 400 mm during vegetative season, from March to October. More precise information regarding the pedo-climatic conditions of the 'Mezzi' farm are reported by Bergante (Bergante et al. 2014). The reference years for the analysis go from 1998 to 2013.

Traditional model of poplar cultivation is a quite intensive model, applied in stands of 250-300 trees per hectare, grown on agricultural soil, with the aim to produce quality wood for the industry. The goal is the production of logs 5 m long, straight and without defects (branches, damages), useful for the production of plywood panels, today the most remunerated product. The residual wood is utilized for sawing, pulp for paper, others panels (OSB, particle panels) and biomass. To obtain high quality wood, trees are irrigated, fertilized, pruned; weeds and disease control are applied when necessary through mechanic intervention or chemicals spreading. In the other model, the plantation of MSA clones allows to avoid some cultural inputs, reducing the number of operations, the chemicals applied and the water use.

To consider the whole cycle of poplar production, three cultivation processes were considered, characterized by different planting layout, densities and crop purpose:

- Stoolbed: is a nursery for massive production and maintenance of different clones from which is possible to obtain a very high amount of poplar cuttings and stems for new plantations (other nurseries, Short Rotation Coppices) establishments. The usual density is approximately 62,500 cuttings ha^{-1}, corresponding to a spacing of 0.10 m between cuttings and 1.60 m between rows. This type or nursery is maintained for 3 years, and every year, at the end of vegetative season, is harvested for cuttings production. The roots are able to re-start in the next Spring. Soil is fertilized after plantation and trees are irrigated during vegetative season. The weeds and disease control were performed if necessary.
- Nursery: is a nursery with lower plantation density, 7,140 trees ha^{-1} corresponding to a spacing of 0.50 m between trees and 2.8 m between the rows. This nursery is made with the plantation of cuttings obtained from stoolbed and is maintained for two years. Trees complete the cycle in two years, with the purpose to produce two years old poplar stems as vegetal material to establish poplar stand. Soil is fertilized, trees are irrigated during vegetative season and weeds and disease controls were performed when necessary. Manual pruning allows to obtain a correct shape and apical dominance of stems.
- Poplar stand: is a final poplar commercial stand in which 278 trees ha^{-1} , derived from nursery, are planted with square layout of 6 × 6 m. Poplar stand grows for 10 years for the production of wood for industry. In the poplar stand soil is fertilized, trees were irrigated, weeds and diseases are chemically and mechanically controlled when necessary.

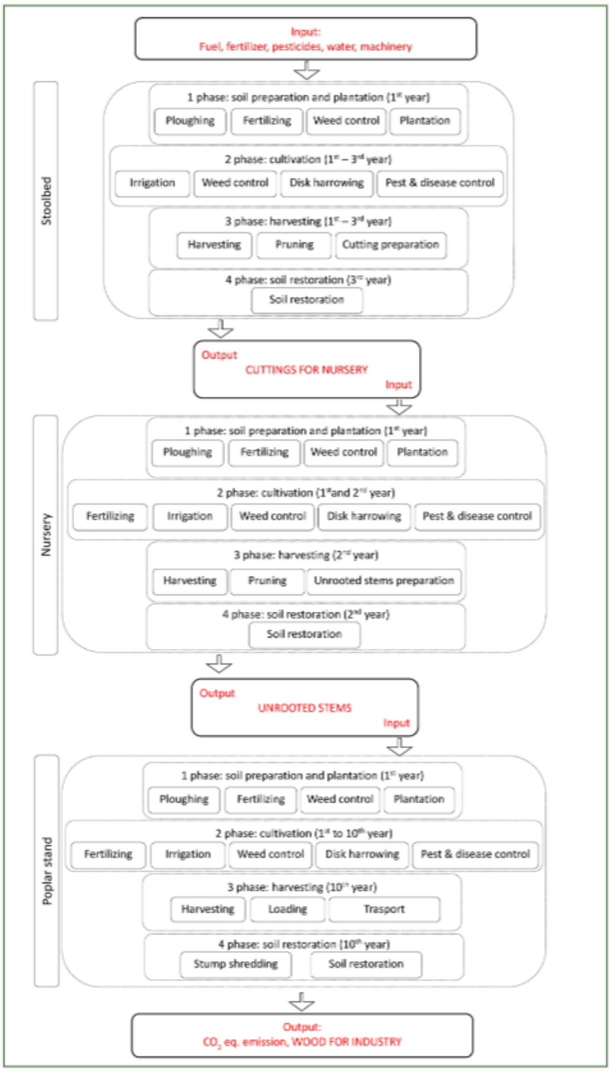
The specific operation carried may vary according to the cultivation model but can be summarized in four main phases:

- Plantation: consists on soil preparation (ploughing, harrowing), fertilization, layout design and mechanical holes opening.
- Cultivation: foresees all the processes that guarantee a good and correct growth of trees, irrigation, weeds control and chemical treatments (when necessary) and pruning for the correct growth.
- Harvest: when tree reached a diameter requested by market, around after ten years, stand is sold. Every tree is felled (through chain saw) and divided in assortments based on quality and market destination.
- Soil restoration: all cultural practices to restore agricultural land to previous conditions.

The LCA analysis applied considers all the processes phases described; the output of each process become the input in the successive one (stoolbed→ nursery→ poplar stand) considering only the amount of output material necessary for the production of 1 ha of successive cultural process; the complete cycle of cultivation from "cradle to gate" considers the cradle as the preparation of the soil for 'stoolbed' plantations and the gate as the soil restoration after harvest (Fig. 1).

All the cultural input, products and material utilized were collected from real experiences on a field trial carried out from 1998 to 2013 at a research station owned by the CREA- Research Centre for Forestry and Wood, Casale Monferrato, Italy, however, some data are not considered in the analysis: in the case of lubricant oil, considering our data and an average consumption from a generic tractor, we calculated that its impact represents 0.12% of the total impact on the cultivation (in the case of 'I-214'; about human labour, with very few exceptions the environmental impacts associated with human labour have systematically been excluded from LCA studies.

Figure 1 - System boundary.



The reason most often argued for this is that labour-force maintenance-related environmental impacts (e.g. food consumption by workers; energy use for shelter; etc.) would occur regardless of the studied system; moreover the nature of labour force in agricultural sector varies widely between the assessed countries, and so the way in which these impacts have been assessed also varies (Lovarelli et al. 2018, Piringer and Steinberg 2006, Milà et al. 2007).

Functional unit

The functional unit provides the reference to which all other data in the assessment are normalized. With LCA's application to agricultural processes, different functional units (FUs) can be selected. In many LCA studies of agricultural production systems, the FU is the area (e.g., 1 ha) (González-García et al. 2013, Bacenetti et al. 2014), nevertheless, for a better understanding of the positive effect obtained with the new clones, it was decided to use the volume (m^3) as further FU because of higher production of MSA clones if compared with 'I-214' and also to analyse, in a future paper, the transformation process in the plywood panel industry where the volume is the common FU.

Life Cycle Inventory (LCI)

All of the inventory data concerning the vegetal material production and poplar cultivation were directly collected from the experience of a 15-year commercial/experimental fields grown in the experimental farm "Mezzi". All the information collected about the soil and vegetal material preparation, plantation and cultivation practices (e.g., the field operations carried out as well as the consumed production factors) and harvesting operations are shown in Figure 2. Background data (Fig. 2) for the production of chemicals were obtained from the Ecoinvent database v3.0. Direct measures of diesel fuel consumption were used as primary data and the related emission were accordingly calculated. Also tractors and equipment (Fig. 2) background calculations were derived from primary data.

Figure 2 - Primary data used in the Life Cycle Inventory for the stoolbed, the nursery and the poplar stand. The input highlighted in gray are only for the 'I-214' clone model, not for the MSA clones.

Cultivation process	Phase	Operation	n.	Machine	Power [kW]	Weight [kg]	Fuel [kg]	Equipment	Product type	Product amount [kg]	Time [h]	Water [m^3]
Stoolbed	1	Ploughing	1	Tractor 4 WD	96	6000	21	plow			2,5	
		Basic fertilization	1	Tractor	70	5000	9,2	spreader	15-15-15	500	1,5	
		Weed control	1	Tractor	70	5000	6,1	barrel	Pendimetalin S-Metolachlor	2,28	1	0,5
		Plantation	1	Tractor	70	5000	184,3	plant machine			30	
	2	Disk harrowing	5	Tractor	30	4000	33,8	harrow			7,5	
		Irrigation	8	Electric pump	14,7						120	2400
		Pest control	7	Tractor	30	4000	9,1	atomizer	Deltametrina	5,6	3,5	5,6
		Disease control	5	Tractor	30	4000	6,5		Dodina	30	2,5	4
	3	Harvesting, pruning, cuttings preparation	1	Tractor	30	4000	3,9	cart			1,5	
	4	Soil restoration	1	Tractor	183	7000	129	shredder			8	
Nursery	1	Ploughing	1	Tractor 4 WD	96	6000	21	plow			2,5	
		Basic fertilization	1	Tractor	70	5000	9,2	spreader	15-15-15	500	1,5	
		Weed control	1	Tractor	70	5000	6,1	barrel	Pendimetalin S-Metolachlor	2,28	1	0,5
		Plantation	1	Tractor	70	5000	73,7	plant machine			12	
	2	Disk harrowing	10	Tractor	30	4000	82,8	harrow			20	
		Fertilizing 2	1	Tractor	70	5000	9,2	spreader	urea	70	1,5	
		Irrigation	16	Electric pump	14,7						240	4400
		Pest control	13	Tractor	30	4000	16,9	atomizer	Deltametrina	10,4	6,5	10,4
		Disease control	12	Tractor	30	4000	6,5		Dodina	72	6	9,6
	3	Harvesting, pruning	1	Tractor	55	5000	9,7	circular saw			2	
		Collection and transport	1	Tractor	55	5000	4,9	cart			1	
	4	Soil restoration	1	Tractor	183	7000	129	shredder			8	
Poplar stand	1	Ploughing	1	Tractor 4 WD	110	6000	24,3	plow			2,5	
		Basic fertilization	1	Tractor	70	5000	3,1	spreader	15-15-15	500	0,5	
		Disk harrowing	1	Tractor	110	6000	14,6	harrow			1,5	
		Soil preparation	1	Tractor	110	6000	14,6	rotary harrow			1,5	
		Plantation	1	Tractor	70	5000	15,4	auger			2,5	
	2	Disk harrowing	20	Tractor	70	5000	292	harrow			30	
		Fertilizing 2	3	Tractor	70	5000	21,5	spreader	urea	270	3,5	
		Pruning	5	Tractor	70	5000	121	lifting platform			19,7	
		Irrigation 1	4	Tractor	70	5000	33,6	barrel			4	100
		Irrigation 2	16	Electric pump	14,7						396	162000
		Pest control 1	7	Tractor	30	4000	29,4	atomizer	Deltametrina	2,8	3,5	3,8
		Pest control 2	2	Tractor	30	4000	8,4	atomizer	Thiamethoxan	0,4	1	3
		Disease control	9	Tractor	30	4000	37,8	atomizer	Dodina	5,98	4,5	6,6
	3	Harvesting, pruning	1	Chainsaw	4	7,4	25,7				70	
		Collection and transport		Tractor	70	5000	150	nipper and cart			24,4	
	4	Shredding stumps		Tractor	183	7000	66,3	auger			4,1	
		Soil restoration		Tractor	183	7000	129	shredder			8	

In some cases, the Ecoinvent data were modified accordingly to the primary data and in relation to the energy mix (many of Ecoinvent's data refer to Swiss productions, instead Italian production) and to the quantities of ancillary materials (we have modified the quantities according to the primary data collected in the study, for example the percentages of the constituent substances of the pesticides and the fertilizers). For each model, the final yield (in cubic meters per hectare) were calculated starting from measures of diameters and total height of trees and utilizing a dedicated software (Chiarabaglio and Coaloa 2004), produced by CREA - Research Centre for Forestry and Wood, in Casale Monferrato (on-line: http://www.populus.it/piopnet3/programmastimapioppeto.zip)

Life cycle impact assessment (LCIA)

The impact on climate change of two models was calculated, comparing the CO_2 eq. total emissions and utilizing the IPCC 100 method. The emissions of each cultural operation were firstly calculated separately, then they have been added to get the total emissions.

Results

The two plantations considered for data collection reached different yields at the end of ten years cycle. The 'I-214' stand produced 158 m^3 ha^{-1}, compared with the MSA stand that reached 197 m^3 ha^{-1}. In the suitable conditions of Po Valley, the MSA stand, with the same cultivation model but with low cultural inputs, allows to obtain +24.7% of raw material; as we will see in the next graphs, this positively affects the results of the analysis.

The GHG emissions per hectare found for the two models, calculated following the IPCC 100 year method, are very similar. For the cultivation of traditional clone 'I-214' total emissions, at the end of cycle, were of 7,347 kg CO_2 eq. per hectare, and were a little greater that emissions produced for the cultivation of MSA clones, that reached 7,218 kg CO_2 eq. per hectare with 9% emissions savings (Fig. 3)

Figure 3 - CO_2 equivalent emissions for 'I-214' and MSA cultivation. Total emissions of the whole cultivation cycle (stoobed+nursery+poplar stand). In red striped the emission avoided choosing the cultivation of MSA.

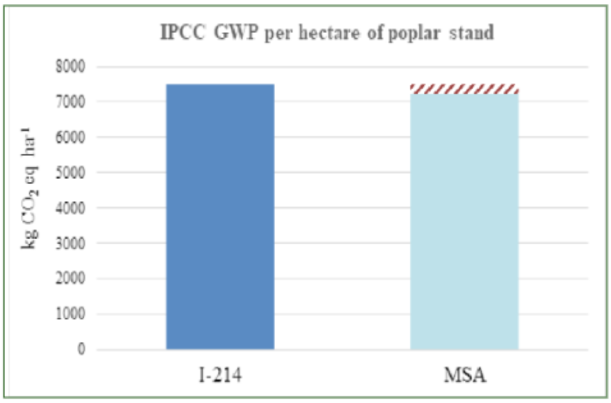
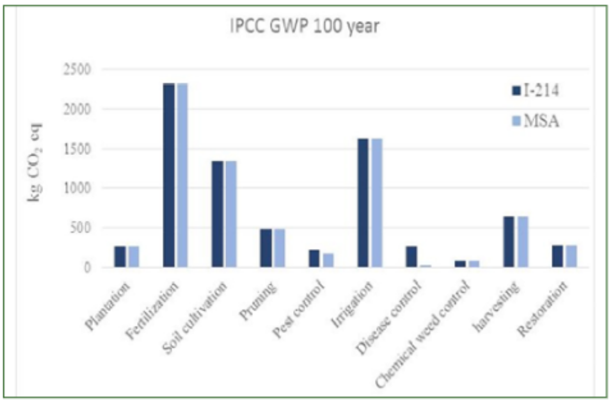


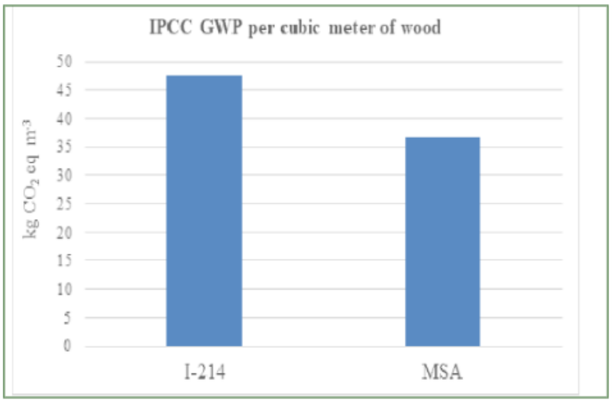
Figure 4 - CO_2 equivalent emissions for 'I-214' and MSA cultivation divided by cultural inputs. Total emissions of the whole cultivation cycle (stoobed+nursery+poplar stand).



Observing the emissions divided by cultural inputs, in Figure 4, three practices in poplar cultivation have a heavy weight on GHG emissions: the fertilization, the irrigation and soil preparation.

The high emissions of fertilization are mainly due to the industrial processes for fertilizers production, especially Nitrogen even if also basic fertilization, spreading operations and air emissions from soil contribute to high values. The high emissions of irrigation practices are strongly related to irrigation method; in our case, in the farm 'Mezzi', one electric pump guarantees the irrigation pushing water under pressure into underground pipelines connected to wells located over the entire area; the use of electricity is high. The operations for soil preparation require high amount of fuel, due to the utilization of powerful tractors. These three practices are the same for 'I-214' and MSA clones, and this is one of the reasons why the emission differences are so low. Differences in the emissions per hectare are obviously concentrated on the two operations 'pests control' and 'disease control'. No chemical products are used for disease control of MSA clones and a very low amount of chemical products and number of interventions are necessary for the pest control of MSA. The emissions avoided are mainly related to the resistance of MSA clones to leaf diseases and to the *Phloeomyzus passerinii* (Sign.).

Figure 5 - CO_2 equivalent emissions for the production on 1 m^3 of 'I-214' and MSA. Total emissions of the whole cultivation cycle (stoobed+nursery+poplar stand).



If the volume yield is considered as FU instead of hectare (Fig. 5), due to the potential higher production per hectare (in the same time) of new MSA clones, the emissions per unit of volume are significantly lower for MSA clones: 36.6 kg CO_2 eq. m^{-3} of MSA, compared with 47.5 CO_2 eq. m^{-3} of 'I-214' saving about 23% of CO_2 eq.

Discussion

The related emissions per cultural input obtained confirm the results of other Authors (Tedeschi et al. 2005, Don et al. 2012). Fertilization, irrigation and soil preparation are the practices with high CO_2 emissions. Some operation for soil preparation can be reduced but for poplar is very important, in the first phases of plantation to grow in well-oxygenated soil free from weeds. Also the irrigation is a very important input for poplar, and in the environmental conditions similar to Po Valley, or in case of higher drought, water is a limiting factor for the growth. Nevertheless, in the suitable areas, can be possible to utilize less expensive methods for water supply exploiting the presence of an accessible water table or the possibility of flooding, without energy expenditure. In many studies has been shown that the poplar can use wastewaters without being damaged, while filtering the amount of nutrients in excess, and for this reason some stand could grow on land irrigated with urban wastewater (Santori et al. 2007, Tanvir et al. 2010, Dimitriou & Aronsson 2011, De Miguel et al. 2014). The environmental (and economic) impact due to irrigation can therefore still be reduced. Fertilization is a widespread practice applied in poplar stands even if in many cases, no positive effects on growth are obtained. Results in the bibliography are contrasting (Amichev and Van Rees 2018) and suggest an important influence of soil and water on the absorption of nutrients (Yin et al. 2009). In the experiences of cultivation in suitable and rich soils of Po Valley, no effects of fertilization were found for poplar growth. Considering these results and the high environmental and economic impact, nitrogen fertilization should be a practice to be evaluated carefully on a case-by-case basis.

The cultivation of MSA clones in suitable conditions allows to avoid a quote of CO_2 emissions, in our case the 9% of emissions, corresponding to approximatively 300 kg CO_2 per ha in ten years. The difference is little and is principally due to chemical avoiding, but also economic and energetic advantages are related. There are other models, linked to certification practices (FSC, PEFC) that could be improve CO_2 saving, and other studies on these aspects are ongoing (Deidda 2018). If the volume is considered as FU, the difference between 'I-214' and MSA clones are more evident: growing the MSA clones a saving of 10.9 kg CO_2 eq. m^{-3} of wood in 10 years is possible. The adult poplar volume (poplar stands ≥ 7 years old) in Italy amount to about 5 million cubic meters and 75% of them derive from 'I-214' clone (Corona et al. 2018). If these plantations were replaced by an MSA clone that produce almost 25% more than 'I-214' and that have lower emissions for their cultivation a reduction of 40,875 tons of CO_2 eq. would be possible. This value corresponds to the emissions of almost 5,660 hectares of poplar stands cultivated with MSA clones, currently equal to 12% of the current area cultivated in Italy.

Conclusions

The new MSA clones give the possibility to produce wood for industry with more sustainable cultivation. The reduction of chemicals could have advantages also in other impact categories like human and animal health toxicity. These new clones will be introduced, probably as a mixture also with 'I-214' in the next poplar plantations thanks to public funding; in this way it will be possible to evaluate the advantages, both from the production and from the environmental point of view, in a wide range of cases related to the different site conditions and farm organization.

References

Amichev B.Y., Van Rees K.C.J. 2018 - *Early nitrogen fertilization effects on 13 years of growth of 4 hybrid poplars in Saskatchewan, Canada*. Forest Ecology and Management 419–420: 110–122.

Bacenetti J., Bergante S., Facciotto G., Fiala M. 2016 - *Woody biofuel production from short rotation coppice in Italy: Environmental-impact assessment of different species and crop management*. Biomass & Bioenergy 94: 209-2019.

Bacenetti J., Fusi A., Negri M., Guidetti R., Fiala M. 2014 - *Environmental assessment of two different crop systems in terms of biomethane potential production*. Science of the Total Environment 466e467 (2014): 1066-1077.

Bergante S., Nervo G., Facciotto G. 2014 - *Biomass production of fast growing species SRC in a marginal soil (Italy)*. In: Proceeding of 22st European Biomass Conference & Exhibition, Hamburg, Germany, 23-26 June: 329-331.

Cellerino G.P., Anselmi N. 1980 – *Poplar diseases situation in Italy in 1979-80*. In: Proceedings of the Working Party on Diseases FAO/IPC/DIS and IUFRO S2.05.03, Kornik (Polonia) September 1-5 1980. 8 p.

Cellerino G.P., Anselmi N. 1982a - *Methods followed by the Poplar Research Institute in Casale Monferrato to value clonal resistance of poplar leaves to Venturia populina*. In: Proceedings of the XXII Session FAO/IPC/DIS, Casale Monferrato 6-8 settembre. 16 p.

Cellerino G.P., Anselmi N. 1982b - *On the susceptibility of* Marssonina brunnea, Melampsora allii-populina *and* Venturia populina *of* Populus deltoides *from Oklahoma*. In: Proceedings of the XXII Session FAO/IPC/DIS, Casale Monferrato 6-8 settembre. 9 p.

Chiarabaglio P.M., Coaloa D. 2004 - *Software per la stima del pioppeto maturo*. Sherwood - Foreste ed alberi oggi 10: (6) 17-20.

Corona P., Coaloa D., Puletti N. 2018 - *Prezzi in rialzo, boccata d'ossigeno per la pioppicoltura* Terra e Vita 34: 66-69.

Deidda A. 2018 – *Il pioppo come materia prima per l'edilizia. Studio ed elaborazione degli impatti, dalla coltura alla produzione di un pannello di compensato, con metodologia LCA*. Thesis, POLITECNICO DI TORINO, Dipartimento di architettura e design. 161 p.

De Miguel A., Meffe R., Leal M., Gonzalez-Naranjo V., Martinez-Hernández V., Lillo J., Martin I., Salas J.J., de Bustamante I. 2014 - *Treating municipal wastewater through a vegetation filter with a short-rotation poplar species*. Ecological Engineering 73: 560-568.

Dimitriou I. Aronsson P. 2011. *Wastewater and sewage sludge application to willows and poplars grown in lysimeters–plant response and treatment efficiency*. Biomass and Bioenergy 35 (1): 161-170.

Don A., Osborne B., Hastings A., Skiba U., Carter M., Drewer J., Zenone T. 2012 – *Land use change to bioenergy production in Europe: implications for the greenhouse gas balance and soil carbon*. GCB Bioenergy 4: 372–391.

González- Garcia S., Mola-Yudego B., Murphy R.J. 2013 - *Life cycle assessment of potential energy uses for short rotation willow biomass in Sweden*. International Journal of Life Cycle Assessment 18 (4): 783 -795.

Krzyzaniak M., Stolarski M. J., Warminski K. 2019 - *Life cycle assessment of poplar production: Environmental impact of different soil enrichment methods*. Journal of Cleaner Production 206: 785-796.

Lovarelli D., Fusi A., Pretolani R., Bacenetti J. 2018 - *Delving the environmental impact of roundwood production from poplar plantations*. Science of the Total Environment 645: 646–654.

Milà L., Muñoz I., McLaren S., Brandão M. 2007 - *LCA methodology and modelling considerations for vegetable production and consumption*. CES Working Paper 02/07, Centre for Environmental Strategy, University of Surrey, Guildford (Surrey) GU2 7XH, United Kingdom.

Piringer G., Steinberg LJ. 2006 - *Reevaluation of Energy Use in Wheat Production in the United States*. Journal of Industrial Ecology 10:149-167.

Santori F., Cicalini A.R., Zingaretti A., Facciotto G., Bergante S. 2007 - *SRF of poplar fertirrigated with olive mill wastewater in demo plant*. In: Proceedings of "15th European Biomass Conference & Exhibition" Berlin, 7-11 May: 687-690.

Tanvir M.A., Siddiqui M.T. 2010 – *Growth performance and cadmium (Cd) uptake by* Populus deltoides *as irrigated by urban wastewater.* Pakistan Journal of Agricoltural Science 47(3): 235-240.

Tedeschi V., Federici S., Zenone T., Facciotto G., Bergante S., Matteucci G., Lumicisi A., Seufert G. 2005 - *Greenhouse gases balance of two poplar stands in Italy: a comparison of a short rotation coppice and a standard rotation plantation*. In: Proceedings of "14th European Conference & Exhibition, Biomass for Energy, Industry and Climate Protection" Paris France: 2014–2016.

Yin C., Pang X., Chen K. 2009 – *The effects of water, nutrient availability and their interaction on the growth, morphology and physiology of two poplar species*. Environmental and Experimental Botany 67: 196–203.