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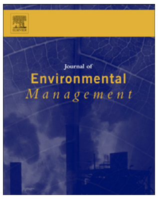

Research article

# Energy input in conventional and organic paddy rice production in Missouri and Italy: A comparative case study

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ABSTRACT

The expected decline in availability of fossil fuels over the next several decades, either because of resource depletion or because of limits on carbon emissions, is leading to a keen interest in finding more sustainable energy sources. For this reason, it is useful to assess the energy footprint of alternative agricultural systems for crops and animal production and to identify potential transition scenarios to systems largely based on renewable energy. The present work aims to assess for the first time a comparative analysis of energy inputs in rice production systems in Southern Europe (Piemonte, Italy) and in North America (Missouri, USA). A total of twelve rice farms, either conventional or organic, were selected, collecting detailed data on direct (fuel and electricity) and indirect (machinery, fertilizers, pesticides, and seeds) energy inputs. While energy input of conventional farms ranged from 3.5 to 7 MJ/kg paddy rice, organic farming could reduce inputs by more than 50% with only 8% yield decrease. A significant reduction in fuel or electricity use can be achieved also with no till and surface irrigation. The use of renewable energy sources, as already practiced by some farms, could more than cover their electrical energy requirements.

## 1. Introduction

Rice (*Oryza sativa*) is one of the world's oldest and most important species used as food. Genetic molecular evidence shows that rice was domesticated between 8000 and 13,000 years ago in China (Ponting, 2007; Molina et al., 2011) and then spread all over the world, reaching Europe probably during the renaissance (Crosby, 2004) and North America a few centuries later, mainly through Africa (Carney, 2001). At the global level, rice is the leading vegetal food in terms of energy intake (19% of the diet) and the second after wheat for protein consumption (12.7%) (FAOSTAT, 2016).

Rice farming requires a significant amount of energy, both in direct (diesel fuel, electricity) and indirect forms (machinery, fertilizers, pesticides, seeds). A number of studies have considered the energy input in rice farming, but most of these are focused on Asia, for example, China (Lu et al., 2010), Malaysia (Bockari Gevao et al., 2005), Japan (Koga and Tajima, 2011; Saga et al., 2010), Philippines (Mendoza, 2002; Quilty et al., 2014), Thailand (Caichana et al., 2014), India (Chaudhary et al., 2006), Pakistan (Pracha and Volk, 2011) and Iran (Agha Alikhani et al., 2013; Eskandari and Attar, 2015; Mohammadi et al., 2014, 2015; Pishgar-Komleh et al., 2011).

Little attention has been paid to rice production in North America and Europe: only two analyses of rice production were performed outside Asia, one on Italy (Blengini and Busto, 2009) and a second on United States (Pimentel, 2006). Despite this limited attention, rice production in Europe and North America covers 650,000 and one million hectares respectively, and the latter exports about 60% of its production. Moreover, in both cases domestic consumption has increased by more than 30% in the last twenty years (FAOSTAT, 2016).

This paper aims to fill this gap by assessing the energy inputs in the rice production systems of one region in North America (Missouri, USA) and one in Southern Europe (Piemonte, Italy). The two case study areas were chosen for their significant production of rice and for the comparable size of population, GDP per capita and cultivated areas, even though Missouri is characterized by larger farms (see Table A1 in the Annex).

The comparative analysis was conducted taking into account four main characteristics of the farms:

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– conventional vs organic agriculture;
– tillage vs no tillage methods;
– surface vs underground sourced water for irrigation; and
– different climatic conditions.

Life Cycle Assessment (LCA) (Curran, 2006; Hendrickson et al., 2006) served as the methodological foundation of this study although the study is only concerned with energy inputs and does not account for other consequences such as raw materials consumption and wastes/emissions. Nevertheless, the adopted methodology (functional unit, system boundaries and approximations, flow diagram), follows a typical LCA structure for energy consumption.

## 2. Materials and methods

An in-depth analysis was performed on 12 rice farms, 5 in Missouri and 7 in Piemonte. Of these, 10 were chemical based (C) and 2 were organic farms (O). Farm details are reported in Table 1. The reason for the limited inclusion of organic farms - one for each region - is related to the limited diffusion of organic farming practices in the two study areas within the specific sector.

The sample, although relatively small, is consistent with most of the above mentioned studies. Farm locations are approximately indicated in Fig. 1. The difference in farm areas between Piemonte and Missouri is similar to the situation at the regional level (Table A1 of annex).

There are two main differences in the way that rice is cultivated in the two regions. The first difference is in the irrigation technology employed. The Piemonte farms benefit from surface irrigation from the Cavour Canal system which feeds a complex network of canals in the provinces of Novara and Vercelli for a total irrigated area of 1540 km$^2$, whilst in Missouri there are no canals and water must be pumped from underground sources. The second difference is related to tillage which is a usual practice in the Italian region, but uncommon in the rice producing region of Missouri.

### 2.1. System boundaries, functional units and approximations

The system boundaries are set "around the farm", in order to consider direct energy inputs and energy embodied in structures (silos and hangars), machinery (tractors, harvesters, etc.) and materials (seed, fertilizers and pesticides).

The inventory flow chart is illustrated schematically in Fig. 2. Direct energy inputs occur in the form of petroleum fuels (tractors and irrigation pumps), natural gas (rice drying) and electrical energy (pumps and drying). Primary energy used for electricity production was determined according to the current energy mix in the two regions (coal, natural gas, nuclear and renewables). Indirect primary energy input for structures, machinery and materials was estimated based on data gleaned from the literature, for which it is not possible to estimate the energy mix. The methods to compute indirect inputs are specified in the following paragraphs.

**Table 1**
Characteristics of the conventional (C) and organic (O) farms surveyed in the present study.

| Farm | | Area (ha) | Yield (t/ha) |
|---|---|---|---|
| Missouri | C1 | 569 | 9.3 |
| | C2 | 142 | 8.0 |
| | C3 | 122 | 8.0 |
| | C4 | 1220 | 8.8 |
| | O1 | 163 | 7.5 |
| Piemonte | C5 | 151 | 7.5 |
| | C6 | 90 | 6.14 |
| | C7 | 20 | 7.00 |
| | C8 | 58 | 5.18 |
| | C9 | 90 | 7.5 |
| | C10 | 71 | 7.24 |
| | O2 | 110 | 6.13 |

All information on direct energy inputs, structures, machinery and materials were collected during field visits and interviews with farmers. The complete list of all indicators obtained from the interviews is reported in Table A1 of the Annex.

The functional unit used in this study is one kg of paddy rice; for this reason, rice husks were not considered as a by-product. Since the dried rice from the farms had moisture levels between 11.5% and 13%, moisture levels were normalized to the most frequent value of 12%, according to the formula $R_C = R\ (1 - m)/(1 - 0.12)$, where $R$ is the actual rice production at final moisture $m$, and $R_C$ is the corrected rice mass at 12% moisture.

The functional unit of 1 ha of cultivated rice was chosen in order to evaluate the performances of farms with different rice yields.

Milling and packaging were not considered since only two farms in the group where equipped with milling facilities and sold their products directly. Allocation of husks was not considered since the system boundary was the farm gate and the functional unit is in terms of paddy rice. Rice straw was not taken into account as a by-product since it is mostly used within the farm as a soil amendment.

The present analysis did not consider second and higher order indirect inputs, like the energy used for building the factories that produced machinery or fertilizers, or the banks that granted the loans, or the law offices that wrote the contracts and so on.

According to the *Economic Input Output Life Cycle Assessment* (Hendrickson et al., 2006), all energy uses ignored in the present analysis count for less than 3.4% (estimates are based on an analysis performed using the www.eiolca.net site and are related to the US 2002 Benchmark Input-Output Tables at producer price, (Hendrickson et al., 2006). Therefore it is possible to assume that the present analysis covers more than 96% of all energy inputs.

### 2.2. Structures and machinery

Embodied energy in steel used for silos is 35.3 MJ/kg for new material and 9.5 MJ/kg for recycled material (Hammond and Jones, 2008). Since in the US about 65% of steel was recycled over the period 2008–2012 (Papp, 2012), the average embodied energy is calculated to be 18.5 MJ/kg of steel. Using mass data from silo manufacturers and assuming a lifespan of 30 years (DLGF, 2011), the estimated specific embodied energy in silos is 0.05 ± 0.01 GJ/m$^3$ year for volumes greater than 50 m$^3$. The embodied energy per unit of rice is therefore 0.08 ± 0.02 MJ/kg (assuming a rice density of 580 kg/m$^3$).

The energy equivalent for the production of machinery is estimated at 80 MJ for every kg of equipment (Stout, 1991). This value has been substantially confirmed by more recent analyses of tractors and equipment (Mikkola and Ahokas, 2010). Indeed, the lower energy input due to the reduction in embodied energy in steel and iron has been compensated by the increase in aluminum and synthetic materials (tanks, cover plates, gear wheel, hoses, etc.) which are more energy intensive than the replaced steel.

Machinery also requires regular repair, service and maintenance; including all these activities increases the total input energy to about 140 MJ/kg (Giampietro, 2002; Mikkola and Ahokas, 2010). Machinery masses were estimated from their power, according to an average mass/power ratio of 60 kg/kW (Lazzari, 2016).

In the USA, the lifespan of machinery was assumed to be 40 years, since according to the agriculture census in the last ten years the average yearly rate of change was around 2.5%, which yields a turnover time of about 40 years for other equipment (USDA, 2012). The lifetime for Italian tractors and harvester-threshers is