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Energy use and carbon emission of conventional and organic sugar beet farming

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ABSTRACT

The efficiency and environmental impact of sugar beet production can be measured using a variety of energy consumption and carbon emission indicators, respectively. The goal of the present study was to analyse the energy and carbon emission indicators of sugar beet production systems that involved different farming methods and farm sizes. More specifically, we analysed the effects of five tillage practices used in conventional farming systems (deep ploughing, shallow ploughing, chiselling, discing, and no tillage), four non-chemical weed control practices used in organic farming systems (inter-row loosening, inter-row cutting and mulching, smothering with white mustard, and thermal control), and five farm sizes (2, 10, 20, 40, and 80 ha). For conventional sugar beet production, the greatest efficiency (efficiency ratio of 9.59, specific energy of 0.41 MJ kg^{-1}, and energy productivity of 2.41 kg MJ^{-1}) were obtained by disc harrow soil loosening on 80-ha farms. For organic production, the lowest energy input (25862 MJ ha^{-1}) and specific energy (0.46 MJ kg^{-1}) and the greatest yield (55.82 t ha^{-1}), energy efficiency ratio (8.21), and energy efficiency (22.16 kg MJ^{-1}) were obtained using inter-row loosening on 80-ha farms. The most environmentally friendly conventional farming process, in terms of carbon emissions (carbon input of 825.7 kg ha^{-1}, carbon emission ratio of 19.75), involved no tillage technology on 80-ha farms, whereas the most environmentally friendly organic farming process (carbon input of 4606 kg ha^{-1}, carbon emission ratio of 4.85) involved inter-row loosening. Farm size also influenced efficiency and environmental impact; as farm size increased from very small (2 ha) to large (80 ha), the total energy input for the conventional and organic farming systems increased from 6.5 to 10.9% and from 7.9 to 9.6%, respectively, and the carbon input decreased from 9.9 to 14.9% and from 3.1 to 4.0%.

1. Introduction

1.1. Farm size

There are over 570 million farms worldwide, of which ~84% are smaller than 2 ha, 10% are between 2 and 5 ha, and only 6% of farms are larger than 5 ha (Lowder et al., 2016). In the European Union (EU-28), the average farm size (i.e., utilised agricultural area, UAA) per agricultural holding is ~16.1 ha (Table 1). UAA is a standardised measure of the land area used for farming, which is defined as arable land, permanent crops and grassland, and kitchen gardens (European Commision, 2016). From 2007 to 2013, the total number of agricultural holdings in the EU-28 decreased from 1.38 million to 1.08 million, and the total UAA increased marginally, from 173.4 million ha to 174.6 million ha, thereby accounting for ~40% of the total land area of the EU-28. Most (66.3%) of the agricultural holdings are small (<5 ha), and the remaining holdings are either 5–20 ha (19.9%), 20–50 ha (7.1%), or >50 ha (6.7%).

The average size of agricultural holdings varies considerably between countries of the EU-28. The largest agricultural holdings (>80 ha average UAA) are in the Czech Republic, Great Britain, and

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Table 1
Distribution of agriculture holdings in the EU-28 (European Commision, 2016).

Farm size (UAA[a])	2007		2010		2013	
	Number	%	Number	%	Number	%
<5	9711890	70.3	8492430	69.3	7186960	66.3
5–10	1584060	11.5	1337660	10.9	1277230	11.7
10–20	1003220	7.3	916570	7.5	888540	8.2
20–30	402680	2.9	382560	3.1	374870	3.5
30–50	406750	2.9	399160	3.3	387730	3.6
50–100	394120	2.9	393890	3.2	388680	3.6
>100	305820	2.2	325860	2.7	336740	3.1
Total	13808480	100	12248040	100	10841000	100
UAA	173376390		175815160		174613900	
Mean	12.6		14.4		16.1	

[a] UAA = Utilised agricultural area (ha).

Slovakia. However, in most countries (n = 12), the average UAA per holding is 20–80 ha. For the remaining countries, ten countries have an average UAA of 5–20 ha, and three have an average UAA of <5 ha. In 2013, the average size of an agricultural holding in Lithuania was 16.7 ha (European Commision, 2016), and since 2005, the country's average holding size has increased by an average of 5.7 ha, which is marginally more than the EU-28's average increase of ~4.2 ha per holding. Previous research in Lithuania has found that the costs of tillage and sowing are highest for very small (2 ha) farms and that increasing farm size to 20 ha reduces these costs by 12–27% ha^{-1}, depending tillage and sowing system (Sarauskis et al., 2012).

1.2. Sugar beet production

Sugar beet (*Beta vulgaris* L.) is the source of nearly 30% of the world's annual sugar production (Dohm et al., 2014; Nieberl et al., 2017), and the EU-28 is one of the world's largest producers of sugar beet. According to Eurostat (2016), EU-28 countries were growing ~1.5 million ha of sugar beet in 2016 and produced ~111.6 million t (74.4 t ha^{-1} on average), which accounted for about half of the world's total production. The largest sugar beet producers in the EU-28 are France, Germany, and Poland, which together produce more than 60.0% of the EU-28's sugar beets (France 31.0%, Germany 22.8% and Poland 12.1%). Lithuania possesses ~15240 ha of sugar beet, and the country's 2016 harvest yielded ~933500 t (61.3 t ha^{-1} on average), which accounted for 0.8% of the EU-28's total production (Eurostat, 2017).

1.3. Agricultural energy use and greenhouse gas emission

Rapid growth in population size and food demand have increased the energy consumption of the agricultural sector (Sefeedpari et al., 2013). Modern agriculture uses highly mechanised technological operations that significantly impact both energy consumption and environmental pollution. Soil tillage, which is one of the most important modern practices, is also the most energy consuming and most expensive practices. In fact, conventional soil tillage that uses a mouldboard plough accounts for 29–59% of all the diesel fuel used for agriculture (Akbarnia and Farhani, 2014; Barut et al., 2011; Filipovic et al., 2006; Koga et al., 2003; Stajnko et al., 2009; Šarauskis et al., 2014). The main objectives of reduced tillage are to increase biodiversity, to preserve the environment, to prevent soil degradation, to reduce the leaching of fertile soil, fertilisers, and other chemicals into water bodies, and to reduce labour, fuel, and overall production costs (Sarauskis et al., 2012).

Previous studies have analysed the energy consumption of producing different crops and the greenhouse gas (GHG) emissions of conventional farming. Barut et al. (2011), for example, analysed the effects of tillage on the energy use of corn silage production along the Mediterranean Coast of Turkey, and Haciseferogullari et al. (2003) investigated the energy balance of sugar beet plants. According to the results of the experiments, the total energy input, total energy output, output/input ratio for sugar beet are found to be 19760, 378491 and 19.2 MJ ha^{-1}, respectively (Haciseferogullari et al., 2003). Meanwhile, Yousefi et al. (2014) results showed that total inputs and output energy for sugar beet growing in western of Iran were 49517 and 1095360 MJ ha^{-1}, respectively. Estimated energy use efficiency was 22.1 and carbon efficiency ratio for sugar beet was 11.0. Studies have also calculated energy use and GHG emission indicators for a variety of field crops, including soybean, rice, potato, sugar beet, and wheat. For example, Alimagham et al. (2017) reported that the GHG emissions of soybean production ranged from 1265 to 2969 kg CO_{2eq} ha^{-1}. For wheat production, the total GHG emission of wheat production in Iran was 1119 kg CO_{2eq} ha^{-1}, with chemical fertiliser and diesel fuel being the greatest contributors (Sefeedpari et al., 2013). Sefeedpari et al. (2013) reported that the energy ratio and GHG emissions were lowest on very large farms and proposed that farm size influenced both energy efficiency and GHG emissions. Chaudhary et al. (2017) reported that direct sowing was more energy efficient than other rice production methods. However, Trimpler et al. (2016) argue that a formal agreement on the calculation of GHG emissions in crop production has yet to be established and conclude that further research and development are needed to improve plant production. Similarly, Lal (2004), who is one of the most cited authors regarding carbon emissions, argues that the broad range of units used to report agricultural inputs makes the comparison of carbon costs extremely complex and that for farm operations it is useful to convert different units of measure to carbon emissions (CE) in kg CE. CE analyses for sugar beet production under traditional and intensive farming systems in Morocco was assessed by Mrini et al., (2002). Total CE calculated as C equivalent in small farms and in large farms were 522 kg CE ha^{-1} and 1078 kg CE ha^{-1}, respectively. The highest indirect CE input was in the form of N fertiliser, which amounted 30.2% for small farms and 21.1% for large farms. While, machinery amounted 11.5% of the CE input for small farms compared with 5.8% for large farms. Total energy outputs were 3263 kg CE ha^{-1} and 4472 kg CE ha^{-1} for small and for large farms, respectively (Lal, 2004). Furthermore, relatively few studies have investigated the energy consumption and efficiency of organic farming systems. Bos et al. (2007) presented results of a model study comparing energy use and GHG emissions in organic and conventional farming systems in the Netherlands. They found, that energy use and GHG emission per Mg product in organic crop production is 5–40% and 7–17%, respectively higher than in conventional systems. Other investigations shows, that energy use in organic farming is 10–30% and GHG up to 15% higher than in conventional farming (Bos et al., 2014). Therefore, the goal of the present study was to analyse the effects of tillage method, weed control method, and farm size on the energy and carbon emissions of conventional and organic sugar beet farms.

2. Materials and methods

2.1. Study site

The experimental research was carried out at the Aleksandras Stulginskis University Experimental Station (54°53′ N, 23°50′ E) during the periods of 2001–2007 and 2015–2016. The soil of the experimental site was classified as a silty light loam, i.e., Planosol (*Endohypogleyic-Eutric Planosol-Ple-gln-w*) (WRB, 2014), and the upper soil layer was composed of 45.6% sand, 41.7% silt, 12.7% of