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Ecological impact of wheat and spelt production under industrial and alternative farming systems

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Abstract

The Industrial Revolution and intensification of agriculture have, in some cases, led to economic activities that profoundly influenced the ecosystem to the point where environmental stability and geographic political security are jeopardized. The uncertainty about oil reserves, rising energy prices and the threat of harmful climate change effects has intensified the search for alternative farming systems that reduce negative environmental impact. This study reports the ecological impact of conventional (CON), integrated (INT), organic (ORG) and biodynamic (BD) farming systems calculated from data collected in a field trial at Maribor, Slovenia, and interpreted using the SPIonExcel tool. This tool is a member of the ecological footprint family and describes the area necessary to embed a human activity sustainably into the ecosphere. Three-year results show a markedly reduced ecological footprint of the ORG and BD systems in production of wheat (*Triticum aestivum* L. 'Antonius') and spelt (*Triticum spelta* L. 'Ebners rotkorn'), mainly due to the absence of external production factors. When yields were also considered, the ORG and BD systems again had a reduced overall footprint per product unit and increased ecological efficiency of production. Thus, ORG and BD farming systems present viable alternatives for reducing the impact of agriculture on environmental degradation and climate change. Nevertheless, room for improvement exists in the area of machinery use in all systems studied and yield improvement in the ORG farming system.

Key words: production systems, organic farming, biodynamic farming, ecological footprint, SPI, ecological efficiency of production

Introduction

The Industrial Revolution and intensification of agriculture have in some cases led, for the first time since the emergence of permanent settlements and agriculture more than 12,000 years ago, to economic activities that profoundly influence the ecosystem to the point where environmental stability and geographic political security are jeopardized[1,2]. Thus, the World Commission on Environment and Development (the Brundtlandt Commission) coined the definition of sustainable development in 1987—it is development that satisfies the needs of current generations without compromising the needs of future generations[3]. In recent years, numerous tools and methods have emerged that are supposed to determine sustainable development on the level of single enterprises[4] as well as on a higher, societal level[5,6]. One of these tools is the environmental or ecological footprint[1]. It aims at estimating the biologically productive area needed to produce materials and energy used by the population of a certain region (city, state and world). The calculated area is compared to the area available to a certain population or individual, called the biocapacity, which presents the productive land and/or water of a region. In cases where the ecological footprint is greater than the biocapacity, human consumption exceeds the natural carrying capacity[7]. Data for the ecological footprint are usually based on statistical data; in the case of agriculture, yearly statistics of individual countries from the Food and Agriculture Organization (FAO) of the United Nations are used. The drawback of such data lies in their inherent inaccuracy, making the footprint less useful for evaluating smaller units, e.g., single farms.

Other tools based on actual and/or real data are more appropriate to evaluate individual production processes.

Table 1. Crop rotation designs for years 2006–2010.

	Crop rotation design 1 (split 1)			Crop rotation design 2 (split 2)		
Year	**Plot 1**	**Plot 2**	**Plot 3**	**Plot 1**	**Plot 2**	**Plot 3**
2006	Clover–grass mixture			Clover–grass mixture		
2007	Clover–grass mixture			Clover–grass mixture		
2008	Wheat	Cabbage	Oil pumpkins	Spelt	Red beet	False flax
2009	Cabbage	Oil pumpkins	Wheat	Red beet	False flax	Spelt
2010	Oil pumpkins	Wheat	Cabbage	False flax	Spelt	Red beet

A framework for applying such evaluation methods is life cycle assessment (LCA), which considers the environmental burden caused by a product, a production process or any activity to provide services[8]. It takes into account the technological processes of all activities along the life cycle, from the provision of basic materials to transportation into and from the production unit to the production process itself and finally the use phase of any product and its safe disposal. It is based on an eco-inventory identifying all material and energy flows exchanged with the environment along the whole life cycle. These flows are then evaluated with an appropriate ecological evaluation method. The result can be interpreted on a per-unit-of-product basis (kg) or equivalent area (ha), where areas used outside of the production unit are included[9]. One drawback of this approach is the limited comparability of the results as they critically depend on the scope of the LCA, which may differ from study to study, even for the same products or services.

Research in the area of the ecological footprint or LCA in agriculture is still developing. In this paper, we will apply ecological evaluation using the LCA framework and compare the production of field crops in different production systems by the Sustainable Process Index® (SPI)[10–13]. This evaluation method has been customized for agriculture, e.g., by introducing an algorithm to account for the impact of seed production. We used experimental data from a systems comparison field trial over 3 years; therefore, results reflect conditions in real-life situations and farming systems. The main question we posed was: how sustainable are the production systems most commonly used today (exemplified by Slovenian wheat and spelt production) and how can they be improved to increase sustainable food production for future generations?

Materials and Methods

Long-term field trial

The experimental site is located at the University Agricultural Centre of the University of Maribor in Pivola near Hoče (46°28′N, 15°38′E, 282 m a.s.l). The annual mean air temperature of the area is 10.7°C; where the mean monthly minimum is in January at 0.4°C and the average monthly maximum is in July at 20.8°C. Average annual rainfall in the area is around 1000 mm. Sixty 7 m × 10 m experimental field plots were established on a dystric cambisol (deep) [average pH value 5.5 (0.1 M KCl solution), soil soluble P at 0.278 $g\,kg^{-1}$ and soil soluble K at 0.255 $g\,kg^{-1}$ in ploughing soil layer], and are maintained within two different five-course crop rotation designs (Table 1). In one rotation there are typical crops for this region [2 years of red clover–grass mixture, winter wheat (*Triticum aestivum* L.), white cabbage (*Brassica oleracea* L. var. *capitata* L. f. *alba*), oil pumpkins (*Cucurbita pepo* var. *styriaca* Greb.]; in the other one there is an alternative crop rotation [2 years of red clover–grass mixture, spelt (*Triticum spelta* L.), red beet (*Beta vulgaris* L.), false flax (*Camelina sativa* L.)]. Since we wanted to compare the same crops in each year of the trial, this resulted in three different combinations of each crop rotation (Table 1). Two years prior to the beginning of the trial a red clover–grass mixture was grown on site and the whole experimental plot was managed according to organic farming standards for 6 years before the trial started in 2007. Four production systems + control plots were arranged in a randomized complete block split-plot design with four replicates, where there were three main plots in each farming system and replicate, which were then split into the two different crop rotations. The farming systems differed mostly in plant protection and fertilization strategies and are defined by the valid legislation and standards (Table 2)—conventional (CON)[14], integrated (INT)[14,15], organic (ORG)[14,16,17], biodynamic (BD)[14,16–18] farming system and control[14] plots, where no fertilization/plant protection was used. Basic soil cultivation, sowing and harvesting dates and methods were identical among experimental plots and were performed on the same dates and in the same manner to adjacent fields (Table 2). Also, the same varieties were used in all farming systems under study (wheat 'Antonius' and spelt 'Ebners Rotkorn'), of conventional origin for CON and INT systems and of organic origin for ORG, BD and control systems.

SPIonExcel tool

The SPI, developed by Krotscheck and Narodoslawsky[11], is based on the assumption that a sustainable economy builds only on solar radiation as natural income. Most natural processes are driven by this income and the Earth's surface acts as the key resource for the conversion of solar radiation into products and services. Global surface area is a limited

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Table 2. Farming systems under investigation in the field trial and differences between them.

Production system	Weed management	Pest management	Manure application
CON farming according to the Slovene agriculture act and GAP	Preventive use of herbicides according to GAP, harrowing when needed	Preventive use of pesticides according to GAP	NPK and N mineral fertilizers used according to GAP and nutrient removal estimates
INT farming according to Slovene standards for Integrated farming	Use of herbicides according to the rules of INT management (harrowing at least once, no preventive use of herbicides)	Curative use of pesticides according to the rules of INT management (i.e., list of allowed products renewed and published every year by the Ministry of Agriculture)	NPK and N mineral fertilizers used based on soil analysis and nutrient removal estimates
ORG farming according to the EC regulation on Organic Farming	Harrowing 1–2 times/season, cover crops after cereals	Crop rotation, harrowing and cover crops	1.4 LU of rotted cattle manure/ha
BD farming according to Demeter International production standards and EC regulation on Organic Farming	Harrowing 1–2 times/season, cover crops after cereals	Crop rotation, harrowing, cover crops, use of BD preparations	1.4 LU of composted cattle manure/ha with added BD compost preparations
Control plots	Harrowing 1–2 times/season	None	None

BD, biodynamic; EC, European Council; GAP, good agricultural practice; INT, integrated farming; LU, livestock units.

resource in a sustainable economy, and anthropogenic as well as natural processes compete for this resource. Therefore, area needed to embed a certain process sustainably into the ecosphere is a convenient measure for ecological sustainability; the more area a process needs to fulfill a service, the more it 'costs' from an ecological sustainability point of view.

Human activities exert impacts on the environment in different ways. On the one hand they need natural resources (e.g., to provide energy, material means of production like fertilizers, etc.), manpower and area for installations. On the other hand they produce emissions and waste besides the intended goods. Therefore, the SPI includes all these different aspects of ecological pressure on the environment and translates them into surface area required by the process. The conversion of mass and energy flows into area is based on two general 'sustainability principles'[13]:

- Principle 1. Anthropogenic mass flows must not alter global material cycles; as in most global cycles (such as the carbon cycle) the flow to long-term storage compartments is the rate-defining step of these dynamic global systems; flows induced by human activities must be scaled against these flows to long-term stores.
- Principle 2. Anthropogenic mass flows must not alter the quality of local environmental compartments; here the SPI method defines maximum allowable flows to the environment based on the natural (existing) qualities of the compartments and their replenishment rate per unit of area.

Further details of this method would be out of scope for this paper; the basic algorithm used in this work is given below and the method is described in detail elsewhere[13,19].

The software SPIonExcel was developed to bring this methodology into an easily applicable form. It is available on the Internet (http://spionexcel.tugraz.at/) and calculates the ecological footprint of a process, product or service given an eco-inventory summarizing the flows to and from the environment over the life cycle in question.

For this paper, the SPIonExcel tool is modified to increase its applicability for agricultural systems, employing slightly different calculation methods compared to the original method (in particular by taking seed production into account) and using a detailed inventory and database for different production systems.

The modified SPIonExcel tool calculates a total ecological footprint (A_{tot}) that is the area necessary to embed the whole life cycle generating a product (e.g., wheat) into the ecosphere. A_{tot} is calculated from 'partial footprints' using the following equation:

$$A_{\mathrm{tot}} = A_{\mathrm{l}} + A_{\mathrm{fp}} + A_{\mathrm{m}} + A_{\mathrm{s}}\ (\mathrm{m}^2), \quad (1)$$

where A_{l} stands for the footprint of direct land use, A_{fp} for the footprint fertilizer and pesticide, A_{m} for the footprint derived for machinery use and A_{s} for the footprint of seed use. Partial footprints were calculated directly from the experimental field trial data, except for the footprints of seed use, which were determined by using Equation 2 from the intermediate footprint (up to seed) of a production system:

$$A_{\mathrm{s}} = \frac{A_{\mathrm{l}} + A_{\mathrm{fp}} + A_{\mathrm{m}}}{Y_a} \times S_a\ (\mathrm{m}^2), \quad (2)$$

where Y_a stands for quantity (in this case the yield of grain) of a crop produced in 1 year and S_a for the quantity of seed used for crop establishment in a year.

Table 3. Sample technological chart for wheat (*T. aestivum* L. 'Antonius') production in the year 2009 with all inputs and machinery use noted.

Measures		Production system					
		Conventional	Integrated	Organic	Biodynamic	Control	
Ploughing	100 HP	2	2	2	2	2	(h, ***)
Seeding	75 HP	0.75	0.75	0.75	0.75	0.75	(h, **)
Fertilization	75 HP	2	1.5	4	4	/	(h, **)
	NPK (7 : 20 : 30)	400	150	/	/	/	(kg ha^{-1})
	N-fertilizer (CAN)	666	406	/	/	/	(kg ha^{-1})
	Potassium salt	/	100	/	/	/	(kg ha^{-1})
	Stable manure/compost	/	/	21,450	18,000	/	(kg ha^{-1})
	BD preparations	/	/	/	BD 502–507 each 8–10 g	/	
Spraying	50 HP	1.5	1	/	2	/	(h, *)
	Herbicide		/	/	/	/	kg
	Boom efekt (glyphosate)	5	/	/	/	/	(l ha^{-1})
	Stomp (pendimethalin) + Axial (pinoxaden)	5.2	5.2	/	/	/	(l ha^{-1})
	Fungicide	/	/	/	/	/	
	Amistar extra (cyproconazole + azoxystrobin)	1	1	/	/	/	(l ha^{-1})
	Insecticide	/	/	/	/	/	
	Fastac (alpha-cypermethrin)	0.12	0.12	/	/	/	(l ha^{-1})
	BD preparations	/	/	/	200 g BD 500 + 15 g BD 501	/	
Harrowing	75 HP	/	1	1	1	1	(h, *)
Harvest	245 HP	0.7	0.7	0.7	0.7	0.7	(h, **)
Yield		5800	4920	2453	3560	2678	(kg ha^{-1})
Seed used		200	200	200	200	200	(kg ha^{-1})

Intensity of machinery use: *, light; **, normal; ***, heavy; HP, horsepower; BD, biodynamic. A detailed description of BD preparations can be found in Turinek et al.[34].

From the attained total ecological footprint, an additional overall footprint per unit was calculated, namely:

$$a_{\text{tot}} = A_{\text{tot}}/Y_a \ (\text{m}^2\,\text{kg}^{-1}), \quad (3)$$

where a_{tot} gives an appraisal of the 'cost' in terms of ecological sustainability of a given product or service by indicating how much surface area is needed to produce one unit of a product, in our case wheat or spelt grain.

The area derived from the above calculation can be related to the surface area that is statistically available to a person in a country, region or area (a_{inh}), which can be obtained from statistical data. This relation then represents the fraction of the 'sustainable ecological budget' for a person consuming the product in question provided by a particular production system. This value is called the SPI[13]:

$$\text{SPI} = \frac{a_{\text{tot}}}{a_{\text{inh}}} \times 1000. \quad (4)$$

As the number would be too small if given on a per-kg basis, it was multiplied by 1000 to give it on a per-ton basis and to better visualize differences between production systems.

The efficiency of a production system in providing a good or service is, however, better expressed through the ecological efficiency of production (EEP) calculated in Equation 5. It provides us with the information on how much of a good or service can be produced on 1 ha of surface area in 1 year with the process or system under study, embedding the provision of this good or service totally and sustainably in the ecosphere:

$$\text{EEP} = \frac{Y_a}{A_{\text{tot}}} \times 10{,}000 \ (\text{kg}\,\text{ha}^{-1}). \quad (5)$$

Data used

All work done on the trial in the years 2008, 2009 and 2010 was carefully monitored and recorded. Data collected from the field trial were transformed into tasks done in a system in 1 year and the time needed for those tasks (e.g., ploughing, seeding, harrowing, spraying, etc.). An example is given for wheat production in the year 2009 (Table 3). Because of the nature of the trial, in which not all operations could be done by machine (e.g., spraying and fertilization), real-life operational times were taken from the University Agricultural Centre Farm, where the experiment took place. The footprint was determined for 1 ha of area.

Table 4. Yields of wheat and spelt depending on production system and year.

Factor	Wheat[1]		Spelt[1]	
	Yield (kg ha^{-1})	Relative yield[2] (%)	Yield (kg ha^{-1})	Relative yield[2] (%)
Production system (PS)				
Control	2467 ± 207c	77	1807 ± 91b	83
CON	4263 ± 469a	133	2260 ± 141ab	104
INT	3683 ± 451ab	115	2369 ± 247a	109
ORG	2450 ± 263c	76	2039 ± 125ab	93
BD	3136 ± 305bc	99	2440 ± 180a	112
Year (yr)				
2008	2530 ± 134b	79	1851 ± 57b	85
2009	3882 ± 431a	121	2550 ± 168a	117
2010	3186 ± 212ab	100	2149 ± 108b	98
Average	3200	100	2183	100
ANOVA				
PS	***		*	
Y	***		***	
PS × Y	n.s.		n.s.	

[1] Wheat yield is given for hulled grain, but spelt yield includes hulls.
[2] Average value of each factor = 100%.
Mean values ± SEs are presented. Different letters indicate statistically significant differences at 95% probability (Duncan test). Levels of significance: n.s., non significant ($P>0.05$); *$P \le 0.05$; ***$P \le 0.001$.

Statistical analysis

Data for the yield, a_{tot}, SPI and EEP were analyzed by multifactor ANOVA with production system and year as factors using Statgraphics Centurion (Version XV, StatPoint Technologies, Inc., Warrenton, VA) and were followed by least squares means comparisons after Duncan[20]. Values given within the paper are means ± standard error (SE).

Results and Discussion

Yields

Yields of wheat and spelt varied among production systems and years (Table 4), with no significant interaction between factors. Highest yields of wheat were attained in the CON production system (4263 kg ha^{-1}), the lowest in the control and ORG production systems (2467 and 2450 kg ha^{-1}, respectively). CON wheat yields were similar to recent average Slovenian wheat yields[21], but lower than those reported by other EU countries. BD and INT systems performed near the average of all farming systems; ORG and control wheat yields tended to be lower (Table 4).

We see a more uniform picture with spelt yields, where differences among production systems are not as accentuated as in the case of wheat. Possibly this is due to the lower breeding modifications of spelt as compared to wheat and the somewhat unresponsive reaction to additional nitrogen fertilizer applications.

For both wheat and spelt, the influence of the production year on yields is significant, where lowest yields were attained in the year 2008 due to significant rain events and thus a delayed harvest (August 7) in that year. Yields in 2009 were above average; 2010, however, gave average yields of both grain crops.

Ecological footprint

The relatively large area appropriated by the CON and INT systems was mostly attributed to mineral fertilizer and pesticide use, while the smaller area appropriated by the ORG and BD systems was mostly due to machinery use (Table 5). For every hectare of CON wheat and spelt production, an additional 52–100 ha of surface area is impacted. The INT system did not perform any better, although it is publicized and advertised as nature-friendlier (compared to the CON system) and as a sustainable agricultural system[15]. Control plots appropriated the least area, which was still seven to eight times greater than the surface area used to plant the crops. In this sense there is great need for improvement in the current agricultural practice and the way we understand, till and work the soil. Furthermore, more efficient machinery and machinery use are a must in order to minimize the impact of agricultural production on the environment.

Overall footprint of a product, SPI and EEP

Results for the a_{tot}, SPI and EEP give an even more insightful picture, as yields are taken into the equation (Table 6). For all three parameters, production systems had a significant influence on the attained results for both wheat and spelt, where control, ORG and BD systems outperformed the CON and INT systems. Production year also significantly influenced the a_{tot} and SPI for wheat production. Moreover, the interaction of production system and year was significant for wheat production. Reasons for

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Table 5. Partial and total ecological footprints of wheat and spelt production for the years 2008–2010 (ha ha^{-1}) for 1 ha of production area.

Production system	Production area	% of total footprint	Seeds	% of total footprint	Machinery use	% of total footprint	Fertilization and plant protection	% of total footprint	Total footprint
	Footprint category								
Wheat									
CON	1.00	1	3.98a	5	6.88c	8	73.36a	86	85.21a
INT	1.00	2	3.40a	5	6.90c	11	52.25b	82	63.54b
ORG	1.00	10	0.69b	7	8.45b	83	0c	0	10.15c
BD	1.00	9	0.58b	5	9.03a	85	0c	0	10.61c
Control	1.00	14	0.46b	6	5.63d	79	0c	0	7.09c
Spelt									
CON	1.00	2	4.90a	8	7.05b	11	48.65a	79	61.60a
INT	1.00	2	3.60b	8	7.01b	15	33.64b	74	45.24b
ORG	1.00	10	0.85c	8	8.45a	82	0c	0	10.30c
BD	1.00	9	0.77c	7	9.25a	84	0c	0	11.02c
Control	1.00	14	0.62c	9	5.63c	78	0c	0	7.25c

Mean values of 3 years are presented. Different letters indicate statistically significant differences between production systems at 95% probability (Duncan test).

Table 6. Overall footprint per unit (a_{tot}), SPI and EEP for wheat and spelt production depending on production system and year.

Factor	Wheat			Spelt		
	a_{tot} (m^2 kg^{-1})	SPI	EEP (kg ha^{-1})	a_{tot} (m^2 kg^{-1})	SPI	EEP (kg ha^{-1})
Production system (PS)						
Control	31 ± 3b	0.48 ± 0.05b	349 ± 30a	43 ± 3c	0.65 ± 0.04c	246 ± 15a
CON	230 ± 22a	3.33 ± 0.28a	49 ± 4c	280 ± 19a	4.26 ± 0.29a	37 ± 2c
INT	204 ± 19a	3.00 ± 0.30a	58 ± 7c	207 ± 21b	3.16 ± 0.32b	53 ± 5c
ORG	47 ± 5b	0.72 ± 0.08b	242 ± 26b	52 ± 4c	0.79 ± 0.06c	202 ± 12b
BD	37 ± 3b	0.57 ± 0.05b	296 ± 29ab	49 ± 4c	0.75 ± 0.06c	219 ± 21ab
Year (yr)						
2008	137 ± 28a	1.99 ± 0.39a	165 ± 26	125 ± 23	1.90 ± 0.35	155 ± 23
2009	96 ± 19b	1.39 ± 0.26b	215 ± 37	137 ± 29	2.08 ± 0.45	154 ± 23
2010	97 ± 19b	1.48 ± 0.29b	217 ± 34	118 ± 20	1.79 ± 0.31	145 ± 22
ANOVA						
PS	***	***	***	***	***	***
Y	***	**	n.s.	n.s.	n.s.	n.s.
PS × Y	**	*	n.s.	n.s.	n.s.	n.s.

Means ± SEs are presented. Different letters indicate statistically significant differences for each factor and indicator separately at 95% probability (Duncan test). Levels of significance: n.s. – non significant (P>0.05); *$P \le 0.05$; **$P \le 0.01$; ***$P \le 0.001$.

these differences between years can be found in lower average yields in the year 2008, where inputs into the systems remained on a similar scale as in the following 2 years.

Ratios between farming systems, where control = 1, provide us with a visual overview as to what influence production systems as such and yields have on the performance of farming systems under study (Fig. 1). Results indicate that higher yields in CON and INT systems can partly compensate for their high footprints. However, there still remains a 6 : 1 ratio for the a_{tot} and SPI between the CON and control system, where EEP does not rise above the ratio 0.2 : 1 for CON : control, whereas it is 0.7–0.9 : 1 for the ORG/BD : control systems, respectively.

Currently, the ORG : CON farmed land ratios in the EU lie from 1 : 830 (Malta), to 1 : 15.4 (Slovenia) and up to 1 : 6.5 (Austria), with the EU-27 average amounting to 3.9% of the total agricultural area being managed organically[22]. Where does that leave us in the future, when we take into account the results from this trial? One of the main objectives to organic farming is that it does not produce enough food to feed the whole population—now and in the future[23]. However, several research projects and reports have demonstrated otherwise[24,25]. Even if yields in

Table 7. Land use for wheat and spelt production in Slovenia in 2010 with the corresponding ecological footprint and projected change with the eventual change of farming practice in 2015 and 2050.

	Wheat				Spelt			
Production system (PS)	Area (ha)	% of total wheat area	Resulting footprint (ha)	Total yield (kg)	Area (ha)	% of total spelt area	Resulting footprint (ha)	Total yield (kg)
Situation in 2010[1]								
CON	18,599	59	1,584,913.60	79,288,006	50	23	3081.81	113,068
INT	12,885	41	818,688.16	47,456,081	24	11	1090.84	57,117
ORG	206	1	2081.29	502,544	143	66	1472.86	291,536
BD	0	0	0	0	0	0	0	0
Total	31,690	100	2,405,683.05	127,246,631	217	100	5645.51	461,721
Projection 2015[2]								
CON	0	0	0	0	0	0	0	0
INT	25,352	80	1,610,796.14	93,371,416	282	10	12,738.14	666,971
ORG	3552	19	36,041.01	8,702,400	2252	80	23,201.56	4,592,497
BD	187	1	1984.60	595,782	282	10	3102.83	686,960
Total	29,091	100	1,648,821.75	102,669,598	2815	100	39,042.53	5,946,427
Projection 2050[3]								
CON	0	0	0	0	0	0	0	0
INT	3169	10	201,349.52	11,671,427	0	0	0	0
ORG	14,625	70	148,395.19	35,831,250	7948	80	81,868.66	16,205,010
BD	4178	20	44,340.35	13,311,108	1987	20	21,897.17	4,847,992
Total	21,972	100	394,085.07	60,813,785	9934	100	103,765.83	21,053,002

[1] Data for area obtained from Ministry of Agriculture, Forestry and Food of Slovenia on the basis of an official email inquiry, based on the number of farms that receive subsidies. Data for yields per hectare are taken from this trial, where organic wheat yields were lower than in previous studies. This is also the reason for the greater reduction in total yields in the 2015 and 2050 projection.
[2] According to the Slovene Action Plan for Organic Farming[35]), 20% of the utilizable agricultural area is planned to be converted to organic farming in 2015. Moreover, due to the planned change of the Common Agricultural Policy and the Slovene Agri-Environmental Programme after 2013, only integrated and organic (biodynamic) farming is under consideration to be subsidized in the future. The proportion of spelt in the total area is projected to increase with years, as spelt is more resistant to pests and diseases and is relatively undemanding and less susceptible to fluctuations in growing conditions. Also less fertilizer input is demanded.
[3] Projection is based on the assumption that by 2050, conventional energy sources (oil, gas, coal and nuclear power) will be in decline and also expensive, thus a shift toward more sustainable, ecologically intensive and less energy-intensive agricultural systems will be a matter of need, rather than choice.

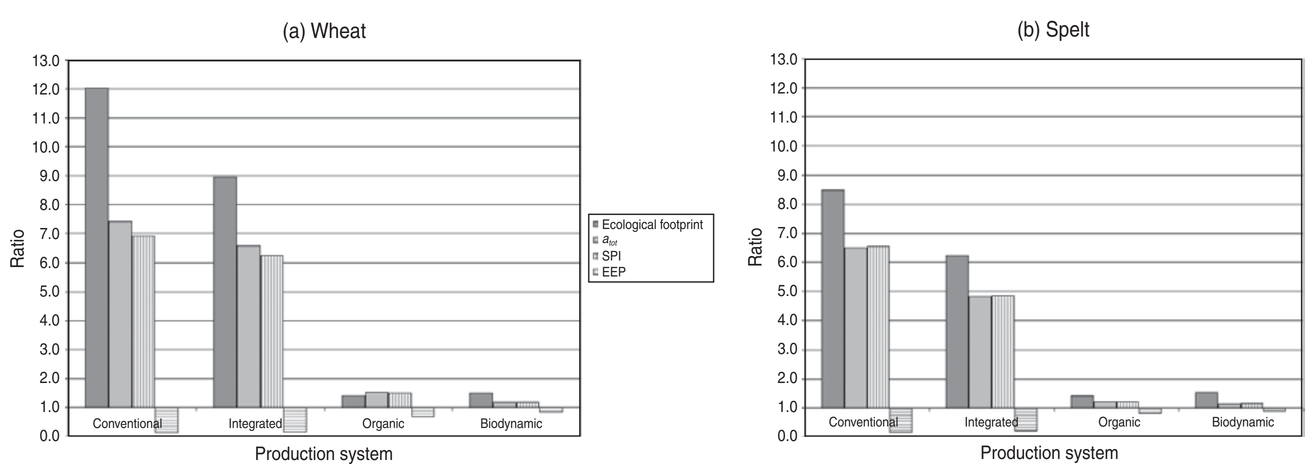

Figure 1. Ecological footprint, overall footprint per unit (a_{tot}), SPI and EEP ratios (control = 1) between production systems for 3 years of wheat (a) and spelt (b) production.

developed European countries, where CON industrial agriculture is now predominant, would be 5–20% lower with ORG and BD agriculture, population projections for developed countries in the next 50 years partly coincide with these lower yields[26]. Next to that, a large proportion of the currently produced grain goes toward feeding animals. In Slovenia alone, feedstuffs for animals are produced on more than three-quarters of the arable land[21]. High

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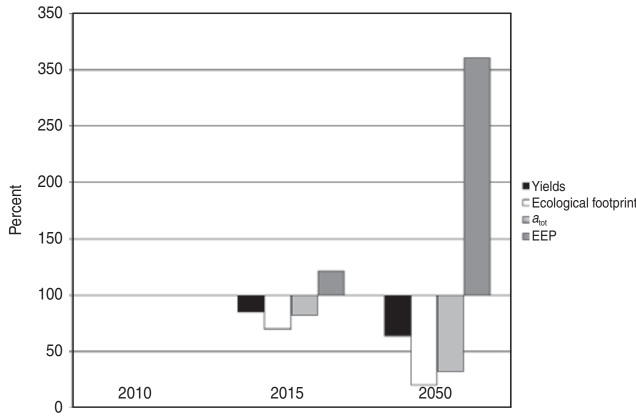

Figure 2. Projected change of total yields, ecological footprint, overall footprint per unit (a_{tot}), and EEP from 2010 (= 100%) to 2050 for wheat and spelt production in Slovenia.

competition for grain and animal manures is also present in the developing 'bio-gas' sector[27]. In this sense there is a relatively great reserve in arable land, which could be used for food, instead of feed or energy production. Taking it a step farther from food production levels, what will happen when oil reserves get depleted? It is important to keep in mind that the relation between population and oil extraction is one of cause and effect. With greater use of mineral fertilizers and pesticides, production of which is based on conventional energy sources, higher yields were achieved in the past century and therefore more people could be fed from the same area than before. However, the downside of this advance in agricultural production is also visible in the results of this research—the high proportion of the final footprint going to mineral fertilizer and pesticide production, caused by using those conventional energy sources and therefore needing a large area to offset the high environmental burden. With abundant oil, a large population is possible—ignoring, of course, the fact that environmental degradation may diminish the human population. Without abundant oil, on the other hand, a large population will not be possible[28]. Fossil oil renewal rates and quantities are much slower than the current usage rates and quantities[28–30], and eventually the era of cheap fossil oil will come to an end. With this in mind we projected the magnitude of change, if all land for wheat and spelt production in Slovenia were converted to organic/biodynamic farming in 2050 (Table 7). Production levels would be lower by almost a third, the ecological footprint and a_{tot}, however, would be lower by almost two-thirds (Fig. 2). Consequently, the EEP would rise threefold compared to the current situation. In 2009, around 170,000 tons of wheat were consumed by the Slovenian population, and an additional 100,000 tons were used for animal feed. More than 45% of that wheat had to be imported[21]. This means that only to nourish people (in order to be self-sufficient) in 2050, twice as much arable land would have to be devoted to wheat production, assuming, of course, the same production levels as with current production techniques. But how can we tackle this issue in the future? Possible solutions can be sought in changing crop rotations and/or land use (as mentioned previously, more than 80,000 ha of land is currently devoted to maize for grain or silage production—mainly for animal feed), but foremost also improving and further developing current alternative agricultural production practices and techniques. In addition, Ewert et al.[31] argue that production levels of the main crops in Europe will rise in the following decades (owing to improved production techniques and a changed climate), and thus less land will have to be cropped to produce the same amount of food. As mentioned previously, efficient use of machinery and the invention of new forms of working the soil will be of crucial importance. Some good examples pointing toward the future can already be seen in practice. One of them is the Eco-Dyn System, where fuel use per hectare has been lowered to 20–30 litres ha^{-1} (it amounted to more than 90 litres ha^{-1} in our study); yields, however, remained stable around the average yields of Germany[32]. Another example is the reinvention and improvement of the ridge-till system[33] in order to lower machinery use and improve the quality of soils and consequently the health of plants and quantity of produce. In both cases the farmers are, next to the technological innovations, using a biodynamic approach toward farm and soil management, which has been found to improve soil fertility in several studies[34]. However, all these improvements and approaches need further research and development in order to adapt them to different microclimatic, pedologic and cultural conditions.

Conclusions

Our results indicate critical points in production of wheat and spelt in each production system, where greatest improvements could be achieved by abandoning mineral fertilizer and pesticide use in industrial farming systems. However, machinery use also needs attention in the near and distant future in all systems studied in order to improve all the recorded parameters and to get closer to sustainable farming systems from a productive and environmental point of view. All mentioned changes will, of course, have to be thought through carefully and support by government policies, economic incentives as well as grassroots activities will aid in making them successful.

The question that stakeholders in agriculture will have to ask in the following years is: Can we save and/or produce enough resources for the current and future generations, when we use or leave an impact on almost 80 ha of surface area to produce 1 ha of wheat (or in a similar size range any other crop)? Or do we have to rethink and above all change the way we farm, live and make decisions in order to survive on planet Earth?

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