ECOLOGICAL EFFICIENCY OF PRODUCTION AND THE ECOLOGICAL FOOTPRINT OF ORGANIC AGRICULTURE

Matjaž Turinek
B.Sc., Young researcher
e-mail: matjaz.turinek@uni-mb.si
Maja Turinek

Silva Grobelnik Mlakar
M.Sc., Senior Lecturer
e-mail: silva.grobelnik-mlakar@uni-mb.si

Franc Bavec
Ph.D., Full Professor
e-mail: franci.bavec@uni-mb.si

Martina Bavec (corresponding author)
Ph.D., Associate Professor

All: Chair of Organic Agriculture, Field Crop, Vegetable and Ornamental Plants
Faculty of Agriculture and Life Sciences
University of Maribor
Pivola 10, SI-2311 Hoče, Slovenia
e-mail: martina.bavec@uni-mb.si

Abstract
Ecological efficiency of production and the ecological footprint of organic agriculture
The rising energy prices and climatic changes have intensified the search for alternative farming systems where energy consumption per unit would be lowered. A long-term field trial, started in 2007 at the University of Maribor, focuses on food quality and the ecological footprint of conventional (CON), integrated (INT), organic (ORG) and biodynamic (BD) farming systems. The gained data has been evaluated and interpreted using the SPIonExcel tool. Results from the first year show better environmental performance of both, ORG and BD systems in production of wheat (*Triticum aestivum* L.) and spelt (*Triticum spelta* L.), mainly due to the non-use of external synthetic production factors. When yields are added to the equation, the ORG and BD systems emerge also as more efficient per unit of land area. Thus, the ORG and BD farming systems present viable alternatives for reducing the impact of agriculture on climate change, while ensuring a more sustainable food security.
Key words
organic agriculture, biodynamic agriculture, ecological footprint, comparison of farming systems

1. Introduction

The world Commission for environment and development (the Brundtlandt Commission) coined the definition of sustainable development in the year 1987 – it is defined as development which satisfies the needs of current generations without compromising the needs of future generations (WCED 1987). Consequences of excessive or unsustainable consumption and production are still evident in the collapsing of global environment system (UNEP 1992). Excessive consumption is addressed towards consumers, production towards companies and organisations which produce goods or offer services (Veleva et al 2001). The industrial revolution and the intensification of agriculture have, for the first time since the permanent settlement pattern and agriculture over 12,000 years ago, led to economic activities which profoundly influence the ecosystem to the point where global environmental stability and geographic political security are jeopardized (Wackernagel and Rees 1996). But it is difficult to determine or implement sustainable development in everyday practice. And it is even harder to measure it. Indicators can help define and communicate questions regarding sustainable development and can also be used to predict and follow the results of political decisions.

According to van der Werf et al (2007), indicators and/or tools for evaluating sustainable development have to be chosen very carefully as regards the method, which best suits the needs, the set goals and the expected results. The tools or indicators known today can be used individually, as several indicators together or as a joined indicator, comprised of more indicators with a single result. Such a single result can be very useful in communicating results to the public or the policy makers. In recent years, numerous tools and methods have emerged which are supposed to determine sustainable development on the level of single enterprises (Veleva et al 2001) as well as on a higher, societal level (Lenzen and Murray 2001; Chen et al 2009). The most of attention is given to the sustainable development of the society due to easy access to databases. One of such tools is also the environ-mental or ecological footprint (Wackernagel and Rees 1996). It tries to summarize the biologically productive area which is needed to produce yearly flows of materials used by the population of a certain region (city, state, world) with all the accompanying waste in the form of emissions (especially CO_2) and the area needed for building infrastructure. In the second step, the calculated area is compared to an area available to a certain population or individual, which is called the biocapacity. In the cases where the ecological footprint is greater than the biocapacity, this means that the human consumption or life standard exceeds the natural carrying capacity (Haberl et al 2001). The data for the ecological footprint is usually excerp-ted from statistical databases, in the case of agriculture from the yearly statistics of individual countries or the food and agriculture organisation. The drawback of such data lays in the inaccuracy of the attained footprint for smaller units e.g. farms.

To evaluate production processes, other tools based on actual/real data are more appropriate. One of such tools is called the LCA (life cycle assessment) and it asse-sses the environmental burden caused by a product, a production process or an activity (Curran 2008). It takes into account the technological processes of all the activities, the basic materials and the transportation into and from the production unit. In the second step, sources used for each input are evaluated by adding the environmental impact, including the resulting emissions and waste. The result can be interpreted on a per unit of product basis (kg) or equivalent area (ha), where areas used outside the production unit are included (van der Werf et al 2007). The

only drawback of this tool is the limited comparability of the gained data on the global or state level. Consequently, the LCA needs to be joined by other indicators or tools.

The research in the area of the ecological footprint or the LCA in agriculture is still developing. According to our present knowledge, there has been no scientific research published on the comparison of production of field crops and vegetables in different production systems using a joint framework of the ecological footprint and the LCA, called the Sustainable process index ® or SPI (Narodoslawsky and Krotscheck 1995; Krotscheck and Narodoslawsky 1996; Sandholzer and Narodoslawsky 2007), which has been customized for agriculture. In this paper, we used experimental data from a long-term field trial. The results therefore reflect the conditions in real-life situations and real-life farming systems. The main question we tied to answer was how sustainable the production systems most commonly used today are, and where they can be improved to sustainably produce food also for the future generations.

2. Materials and methods

2.1 Long-term field trial

Tab. 1: Production systems used and differences among them.

Production system	Soil cultivation and basic operations	Weed management	Pest management	Manure application
Conventional farming (CON) according to the Slovene Agriculture Act and good agricultural practice (GAP)	Ploughing, seedbed preparation, sowing, harvesting	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
Integrated farming (INT) according to the standards for integrated farming (MKGP 2002 and 2004)	Ploughing, seedbed preparation, sowing, harvesting	Use of herbicides according to the rules of INT management, harrowing at least once	Curative use of pesticides according to the rules of INT management	NPK and N mineral fertilizers used based on soil analysis and nutrient removal estimates
Organic farming (ORG) according to the EC regulation 834/2007	Ploughing, seedbed preparation, sowing, harvesting	Harrowing 2-5 times/season, cover crops after cereals, weed burning in vegetables	Use of some natural pesticides (Neem-oil, BT extract) on vegetable crops when needed	1,4 livestock units (LU) of cattle manure /ha
Biodynamic farming (BD) according to the Demeter International production standards	Ploughing, seedbed preparation, sowing, harvesting	Harrowing 2-5 times/season, cover crops after cereals, weed burning in vegetables	Use of BD preparations, some natural pesticides (Neem-oil, BT extract) on vegetable crops when needed	1,4 livestock units (LU) of composted cattle manure /ha with added BD compost preparations
Control plots	Ploughing, seedbed preparation, sowing, harvesting	Harrowing 1-3 times/season	none	none

Farming system definition sources: MKGP 2002; MKGP 2004; EC 834/2007 2007; MKGP 2008; Demeter International e.V. 2009.

The experimental site is located at the University Agricultural Centre of the University of Maribor in Pivola, near Ho(e, Slovenia (46°28' N, 15°38' E, 282 m a.s.l). The yearly mean air temperature of the area is 10.7 °C; with the mean monthly minimum in January with 0.4 °C, and the average monthly maximum in July with 20.8 °C. The average annual rainfall in the area is around 1000 mm. In 2007, thirty experimental field plots (7m×10m) were set up on a dystric cambisol (deep) (average pH value 5.5 (0.1 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, where various sequences of crops in the crop rotations are used. In one such rotation, there are typical crops of this region (two years of red-clover grass, wheat, white cabbage, oil pumpkins). The other one is an alternative crop rotation (two years of red-clover grass mixture, spelt, red beet, false flax). Four production systems with control plots were arranged in a randomised complete block split-plot design with four replicates. The farming systems differed mostly in plant protection and fertilization strategies (Tab. 1). Soil cultivation, sowing and harvesting were identical among experimental plots and were performed on similar dates and in a similar manner than at the adjacent fields.

2.2 SPIonExcel tool

In order to include easily applicable tools that give an overall picture of environmental impacts of products and processes and on top of that offer insights into the steps of a life cycle that exert the largest environmental pressures, the life cycle assessment using the Sustainable Process Index (SPI), a member of the ecological footprint family, is well suited for this task.

The Sustainable Process Index (SPI), developed by Krotscheck and Narodoslawsky (1996), is based on the assumption that a sustainable economy builds only on solar radiation as a natural income. Most natural processes are driven by this radiation on the earth's surface, and for the conversion of radiation into products and services surface area is needed. Surface area is a limited resource in a sustainable economy because earth has a finite surface. Therefore area is a convenient measure for the SPI; the more area a process needs to fulfil a service, the more it "costs" from the point of view of ecological sustainability. Human activities exert impacts on the environment in different ways. On the one hand, they need resources, energy, manpower and area for installations. On the other hand, they produce emissions and waste besides the intended goods. Consequently, the SPI includes all these different aspects of ecological pressure on the environment.

The SPI method is based on the comparison of natural flows with the flows generated by a technological process. The conversion of mass and energy flows into the area is based on two general "sustainability principles" (Sandholzer and Narodoslawsky 2007):

∞ Principle 1 - Anthropogenic mass flows must not alter global material cycles. As in most global cycles (e.g. 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.

We will not go into further detail as regards this method, for it is described in several research papers (e.g. Krotscheck and Narodoslawsky 1996; Sandholzer and Narodoslawsky 2007). However, the SPIonExcel was developed to bring this methodology into an easily applicable form. It calculates the ecological footprint of a process and the SPI of a product or service through the input that characterizes the process given by an eco-inventory. The eco-inventories used for the calculation of the overall footprint contain engineering mass and energy flows of processes in terms of input and output flows (Sandholzer and Narodoslawsky 2007).

For the needs of this research project, our research team met with the developers of the SPIonExcel tool several times in the years 2005-2007, and the result of this is a modified, a more detailed inventory and database for the calculation of the ecological footprint of different production systems.

From the attained footprint an additional ecological efficiency of production systems was calculated using the following equation:

$$\textit{Ecological efficiency of production} = \frac{\textit{Ecological footprint}}{\textit{Yield}} \quad (1)$$

The SPI as calculated by Eq. (1) gives an indication of the "cost" in terms of ecological sustainability of a given product or service (Sandholzer and Narodoslawsky 2007). The number indicates what fraction of the overall "ecological budget" of a production system is used to provide this good or service - in our case 1 kg of wheat or spelt grain.

2.3 Data used

All the work performed on the trial in the season 2007/2008 was carefully monitored and recorded. The data collected from the field trial was transformed into tasks performed in a system in a year and the time needed for those tasks (e.g. ploughing, seeding, harrowing, spraying, etc.). Not all the operations could be done by a machine (e.g. spraying) due to the nature of the trial, therefore 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.

2.4 Statistical analysis

The data for the yield and energy efficiency of production were analysed by one-way ANOVA with the production system as a factor using Statgraphics Centurion (Version XV, StatPoint Technologies, Inc., Warrenton, VA) and were followed by comparison of means according to Duncan (Hoshmand 2006). The values given in this paper are the means ± standard error (SE). We excluded one repetition due to extremely low yields in some parcels, as it was a wet year and water logging occurred in some parts.

3. Results and discussion

Yields of wheat and spelt were below the average levels in Slovenia, mainly due to the late harvest (August 8th) as a consequence of a long rainy period that year. As regards wheat, the yield differences between production systems were insignificant, whereas some differences can be observed as regards spelt yields (Tab. 2).

Tab. 2: Yields of wheat and spelt depending on production system in the season 2007/2008 (at 12% moisture).

	Wheat yield (kg/ha)	Index of wheat yield (CON=100)	Spelt yield (kg/ha)	Index of spelt yield (CON=100)
Farming system	n.s		*	
Control	1,687±267	72	1,630±64[ab]	103
CON	2,343±240	100	1,583±110[ab]	100
INT	2,440±222	104	1,403±125[b]	89
ORG	2,223±356	95	1,533±97[ab]	97
BD	2,400±368	102	1,867±40[a]	118

Means ± SE, n=3. Different letters indicate statistically significant differences at P<0.05 (Duncan test).
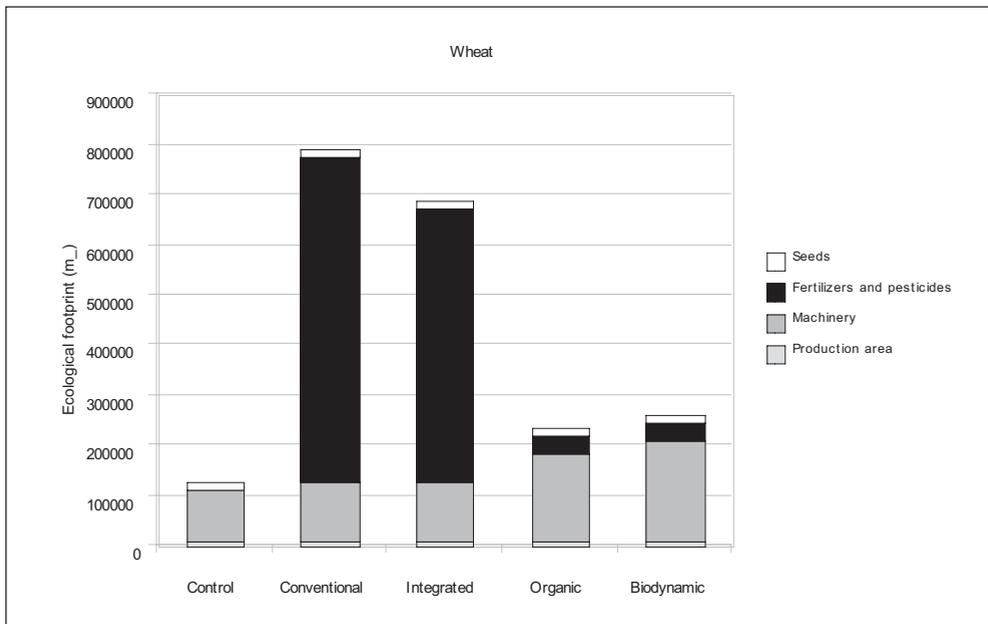

Fig. 1: Ecological footprint for 1 ha of wheat production in the season 2007/2008.

The results of the ecological footprint of production systems for wheat and spelt show a high proportion of the final footprint with CON and INT systems derives from the use of mineral fertilizers and pesticides (Fig. 1 and Fig. 2). However, ORG and BD systems have higher footprints in the field of machinery use impacts, mainly due to manure spreading, harrowing and the use of BD preparations with the BD system. What is surprising is that also control plots for wheat and spelt production have an ecological footprint of 126,168.4 m^2 and 116,469.7 m^2 respectively. This means that by using current standard machinery to till the soil and produce crops, we already leave a great environmental impact and "consume" 11-12 times more land than needed to plant the crops. In this sense, there is great need for improvement in the current agricultural practice and the way we understand, to till and work the soil. Furthermore, alternative fuels (e.g. plant oils) and more efficient machinery are a must in order to minimize the impact of agricultural production on the environment. However, when the total ecological footprint area of CON wheat

and spelt production, which amounts to 792,646.8 m^2 and 537,668.6 m^2 respectively, is visualized it takes some effort to perceive and take into consideration the vast impact the industrial way of farming has on the environment and ecosystems. The INT system does not perform any better, although it is publicised and advertised as more nature friendly and as one of the sustainable agricultural systems (MKGP 2004).
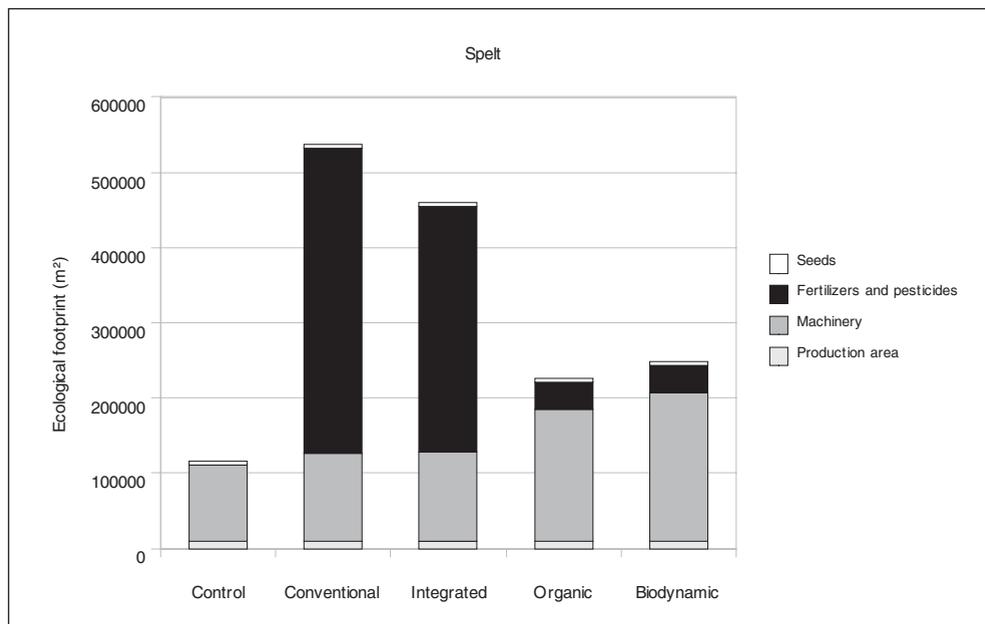

Fig. 2: Ecological footprint for 1 ha of spelt production in the season 2007/2008.

The results of the ecological efficiency of production give an even more insightful picture, as yields are taken into the equation (Fig. 3 and Fig. 4). When compared to the CON system, significantly higher efficiency (4.39, 3.08 and 3.03 times higher) was attained with the use of the control, ORG and BD farming systems for wheat production, respectively. Similar values can be observed for spelt production, where the control, ORG and BD plots had a 4.77, 2.29 and 2.56 times higher efficiency of production when compared to CON plots, respectively. One has to keep in mind, however, that these are the results for the first year of grain production after grass-clover, thus values and ratios will probably change in the next 2-3 years of the trial, and control plots are expected to produce significantly lower yields. Despite this fact, the ORG and BD systems would still have significantly higher ecological efficiencies of production.

But where can improvements be made in the future? As previously mentioned, efficient use of machinery and inventing new forms of working the soil will be of crucial importance. Some good examples pointing towards the future can already be seen in practice, e.g. the Eco-Dyn System (http://www.eco-dyn.de) or converting diesel engines to drive only on plant oil (http://www.elsbett.com). To discontinue the use of mineral fertilizers and pesticides would obviously improve the ecological footprint and environmental efficiency of the nowadays prevalent CON and INT farming systems.
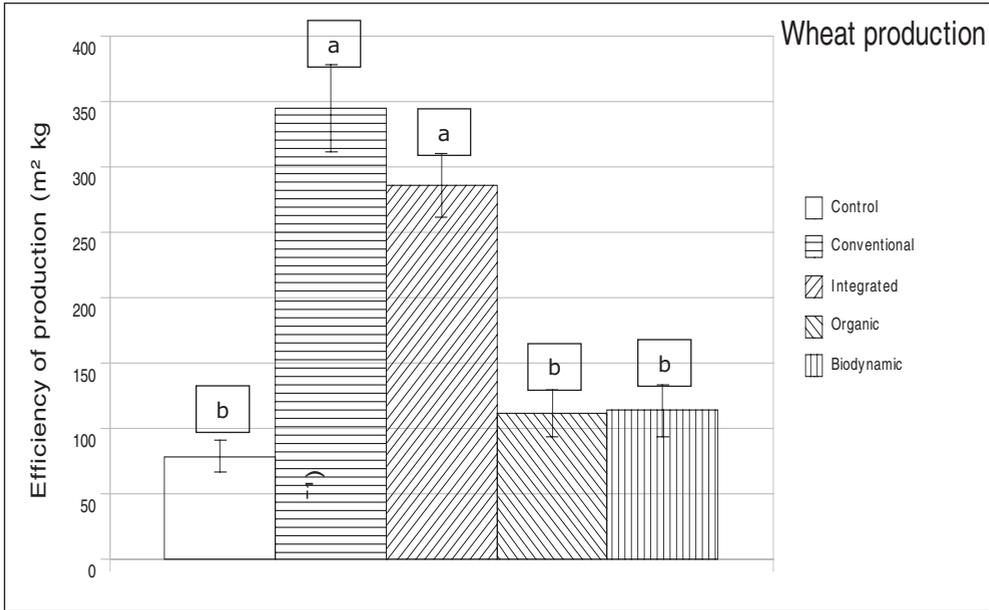
Fig. 3: Efficiency of wheat production for the season 2007/2008 in m^2 of impact for 1 kg of produced grain.
Means ± SE, n=3. Different letters indicate statistically significant differences at P<0.05 (Duncan test).

Figure 4: Efficiency of spelt production for the season 2007/2008 in m^2 of impact for 1 kg of produced grain.
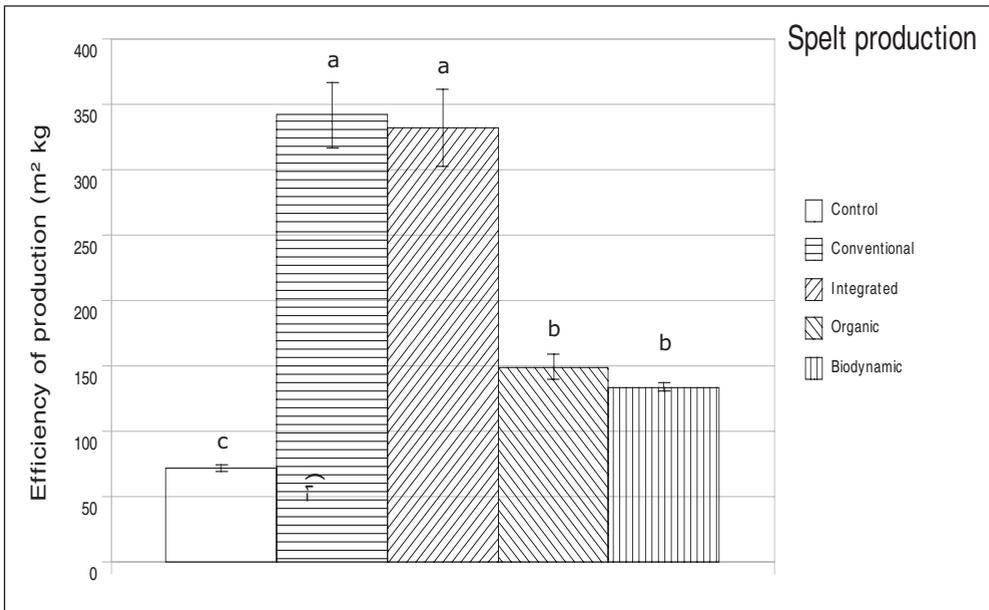Means ± SE, n=3. Different letters indicate statistically significant differences at P<0.05 (Duncan test).

It needs to be added that nowadays, the ORG:CON farmed land ratios in the EU are from 1:830 (Malta) to 1:6.48 (Austria), with the EU-27 average amounting to 3.9% of the total agricultural area (Willer et al 2009).

Where will that bring us in the future, when the results from this trial will be taken into account? One of the main objectives against organic farming is that it does not produce enough food to feed the whole population – now as well as in the future (Avery 2007). However, several research projects and reports have demonstrated the oposite (Badgley et al 2007), including this one. Even if yields in the developed European countries, where CON industrial agriculture is predominant nowadays, are around 5% lower due to ORG agriculture, population projections for the next 50 years coincide with these lower yields in almost the same ratio (UNPP 2008). Taking a step further from the production levels, what will happen when we run out of oil? It is important to keep in mind that the relation between population and oil production is one of cause and effect. The sky-rocketing of population is not merely coincident with the sky-rocketing of oil production. It is the latter that actually causes the former. With abundant oil, a large population is possible - ignoring, of course, the fact that environmental degradation may eventually wipe out those human numbers anyway. Without abundant oil, on the other hand, a large population is not possible (Goodchild 2007).

So can we preserve and provide enough resources for future generations, although we use or leave an impact on almost 80 ha of land to produce 1 ha of wheat (or any other crop in a similar size range)? Or do we have to re-think and above all change the way we live, farm and take decisions in order to survive on Earth? After all, there is only one planet Earth, is there not?

References

Avery, A. 2007: Organic abundance report: fatally flawed. Renewable Agriculture and Food Systems, 22(4), p. 321-323.

Badgley, C. et al 2007: Organic Agriculture and the Global Food Supply. Renewable Agriculture and Food Systems, 22(02), p. 86-108.

Chen, G. et al 2009: Exergetic assessment for ecological economic system: Chinese agriculture. Ecological Modelling, 220(3), p. 397-410.

Curran, M. 2008: Life-Cycle Assessment. In: Encyclopedia of Ecology. Oxford, Academic Press, p. 2168-2174.

Demeter International e.V. 2009: Production Standards for the use of Demeter, Biodynamic and related trademarks. Available at: http://demeter.net/standards/st_production_e09.pdf.

EC 834/2007, 2007: Council Regulation (EC) No. 834/2007 of 28 June 2007 on organic production and labelling of organic products and repealing Regulation (EEC) No. 2092/91. Available at: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2007:189:0001:0023:EN:PDF (February 2, 2009).

Goodchild, P. 2007: Peak Oil And Famine: Four Billion Deaths. Available at: http://www.countercurrents.org/goodchild291007.htm   (Accessed   September 20, 2009).

Haberl, H., Erb, K., Krausmann, F. 2001: How to calculate and interpret ecological footprints for long periods of time: the case of Austria 1926-1995. Ecological Economics, 38(1), p. 25-45.

Hoshmand, A. R. 2006: Design of Experiments for Agriculture and the Natural Sciences Second Edition 2nd ed.. Chapman & Hall/CRC.

Krotscheck, C., Narodoslawsky, M. 1996: The Sustainable Process Index a new dimension in ecological evaluation. Ecological Engineering, 6(4), p. 241-258.

Lenzen, M., Murray, S. A. 2001: A modified ecological footprint method and its application to Australia. Ecological Economics, 37(2), p. 229-255.

MKGP, 2004. Pravilnik o integrirani pridelavi poljščin. Available at: http://www. uradni-list.si/1/objava.jsp?urlid=200410&stevilka=438 (Accessed February 2, 2009).

MKGP, 2002: Pravilnik o integrirani pridelavi zelenjave. Available at: http://www. uradni-list.si/1/objava.jsp?urlid=200263&stevilka=3051.

MKGP, 2008: Zakon o kmetijstvu. Available at: http://www.uradni-list.si/1/objava. jsp?urlid=200845&stevilka=1978 [Accessed September 20, 2009].

Narodoslawsky, M., Krotscheck, C. 1995: The sustainable process index (SPI): evaluating processes according to environmental compatibility. Journal of Hazardous Materials, 41(2-3), p. 383-397.

Sandholzer, D., Narodoslawsky, M. 2007: SPIonExcel-Fast and easy calculation of the Sustainable Process Index via computer. Resources, Conservation and Recycling, 50(2), p. 130-142.

UNEP, 1992: Rio Declaration on Environment and Development. Available at: http://www.unep.org/Documents.Multilingual/Default.asp?documentID=78&articleID=1163.

UNPP, 2008: World Population Prospects: The 2008 Revision Population Database. Available at: http://esa.un.org/unpp/.

Veleva, V. et al 2001: Indicators of sustainable production. Journal of Cleaner Production, 9(5), p. 447-452.

Veleva, V., Bailey, J., Jurczyk, N. 2001: Using Sustainable Production Indicators to Measure Progress in ISO 14001, EHS System and EPA Achievement Track. Corporate Environmental Strategy, 8(4), p. 326-338.

Wackernagel, M., Rees, W.E. 1996: Our écological footprint, New Society Publishers.

WCED, 1987: Our Common Future, Oxford Paperbacks.

Van der Werf, H.M. et al. 2007: Environmental impacts of farm scenarios according to five assessment methods. Agriculture, Ecosystems & Environment, 118(1-4), p. 327-338.

Willer, H. et al. 2009: The European Market for Organic Food and Drink. Available at: http://orgprints.org/15482/ (Accessed September 20, 2009).

ECOLOGICAL EFFICIENCY OF PRODUCTION AND THE ECOLOGICAL FOOTPRINT OF ORGANIC AGRICULTURE
Summary

The rising of energy prices and climatic changes have intensified the interest in the search for alternative farming systems, where energy efficiency would consistently increase and consequently energy consumption per unit would be lower. Several studies and comparisons have been made which compare energy efficiency of different farming systems; however, they mainly focus only on conventional and organic agriculture.

A long-term field trial, started at the University of Maribor in 2007, focuses on food quality and the ecological footprint of conventional (CON), integrated (INT), organic (ORG) and biodynamic (BD) farming systems. All inputs and outputs in each of the farming systems are carefully monitored. The data gained is evaluated and interpreted using the SPIonExcel tool, an ecological footprint calculator of the next generation developed by the Technical University of Graz. The results from the first year show better performance of both, the ORG and BD systems in the production of wheat (*Triticum aestivum* L.) and spelt (*Triticum spelta* L.), mainly due to the non-use of external production factors, such as mineral fertilizers and pesticides. However, the ecological footprint for machinery use is greater in the INT, ORG and BD systems, due to the harrowing needed in all the three systems. When yields are added to the equation, the ORG and BD systems prove to be more ecologically efficient in terms of land area "cost" per unit of yield. Thus, the ORG and BD farming systems represent viable alternatives for reducing the impact of agriculture on climate change, while ensuring sustainable food security.