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Ph. D. THESIS

COMPARABILITY OF THE BIODYNAMIC
PRODUCTION SYSTEM REGARDING AGRONOMIC,
ENVIRONMENTAL AND QUALITY PARAMETERS

DOKTORSKA DISERTACIJA

PRIMERLJIVOST BIOLOŠKO DINAMIČNEGA
PRIDELOVALNEGA SISTEMA GLEDE NA
AGRONOMSKE, OKOLJSKE IN KAKOVOSTNE
PARAMETRE

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Comparability of the biodynamic production system regarding agronomic, environmental and quality parameters

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Abstract

Biodynamic (BD) agriculture became the subject of research efforts during the last decades, whereas a part of the scientific community looks at the BD method with skepticism and marks it as dogmatic. Summarized data of published research studies showed that further research is needed in the field of food quality comparison/determination, food safety and the environmental performance (e.g. foot prints). In this sense, yields, agronomic efficiency (AE) in relation to yields in some crops and the earthworm populations depending on those crops remain to be explored under the BD production system (PS). Therefore wheat, cabbage and oil pumpkins (rotation 1) and spelt, red beet and false flax (rotation 2) were produced in three successive years (2008-2010) under 4 PS (conventional (CON), integrated (INT), organic (ORG) and BD) + control plots in a field trial on the estate of the Faculty of Agriculture and Life Sciences in Pivola near Maribor, Slovenia. Earthworms were determined in rotation 1 in October 2009 and 2010 using the „hot“mustard-extraction method. Yields in the BD PS amounted to 99, 113 and 124 percent of the average yields of all PS for wheat, cabbage and oil pumpkin seeds, respectively. Also AE of N, N_{min}, P and K of the BD system for the production of all crops studied in rotation 1 was in the upper half of all PS under investigation. Moreover, earthworm populations and biomass were significantly highest and on a similar level in the BD and ORG systems in all three crops investigated, where most were found in oil pumpkins. In the second step the ecological footprint of PS under study was calculated for wheat and spelt production and interpreted using the SPionExcel tool. Three-year results show a markedly lower ecological footprint of the ORG and BD systems in production of both crops, mainly due to non-use of external production factors. When yields are added to the equation, the ORG and BD systems also have a significantly lower overall footprint per

product unit and higher ecological efficiency of production. Thus, ORG and BD systems present viable alternatives in facing environmental degradation and climate change in cereal production. However, room for improvement exists in the area of machinery use in all systems studied and yield improvement in the ORG farming system. Moreover, the importance of food quality has increased, but there remains a lack of research in this field, including sensory quality. Thus, in the third step, yields and sensory properties of white cabbage and red beet were examined in 2008 and 2009. Yields did not differ significantly among PS. A total of 167 consumers scored four attributes (color, odor, taste, and willingness to buy) using a nine-point hedonic scale. Results show significant differences between PS for both crops, where INT and control cabbage was preferred over CON cabbage samples (BD and ORG in-between), whereas BD and control red beet was preferred over CON and INT samples (ORG in-between). Lastly, the contents of sugars, organic acids, total phenolic content and the antioxidant activity were quantified in the flesh of red beet samples from 2009 using established methods. Significant differences were measured for malic acid, total phenolic content (TPC) and total antioxidant activity, where malic acid content ranged from 2.39 g kg⁻¹ FW (control) to 1.63 g kg⁻¹ FW (CON, ORG and INT). Highest TPC was measured in BD and control samples (0.677 and 0.672 mg GAE g⁻¹, respectively), lowest in CON samples (0.511 mg GAE g⁻¹). Antioxidant activity was positively correlated with TPC ($r^2=0.6187$) and ranged from 0.823 μ M TE g⁻¹ FW to 1.270 μ M TE g⁻¹ FW in CON and BD samples, respectively, whereas total sugar content ranged from 21.03 g kg⁻¹ FW (CON) to 31.58 g kg⁻¹ FW (BD). The importance of the measured constituents for human health, as well as for plant resilience and health is discussed and put into perspective. Thus, the BD PS presents a viable alternative to the nowadays predominant CON and INT PS for the production of the studied crops under the Slovene subcontinental temperate climate.

Keywords:

biodynamic farming; agronomic efficiency; earthworms; ecological footprint; sensory quality; chemical composition

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Primerljivost biološko dinamičnega pridelovalnega sistema glede na agronomske, okoljske in kakovostne parametre

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Izvleček

Biološko dinamično (BD) kmetijstvo je postalo predmet raziskav v zadnjih desetletjih, a del znanstvene skupnosti še vedno skeptično gleda na BD metodo in jo označuje kot dogmatično. Zbrani izsledki objavljenih znanstvenih raziskav so pokazali, da so potrebne nadaljnje raziskave na področju določitve/primerjave kakovosti hrane, varnosti hrane in okoljske učinkovitosti (npr. okoljski odtis). V tem smislu ostajajo v BD pridelovalnem sistemu (PS) pridelki, agronomska učinkovitost (AU) v odvisnosti od pridelkov pri nekaterih poljščinah in populacija deževnikov v odvisnosti od teh istih poljščin, še neraziskani. Zato smo pridelali pšenico, zelje in oljne buče (kolobar 1) ter piro, rdečo peso in oljni riček (kolobar 2) v treh zaporednih letih (2008-2010) v štirih PS-jih (konvencionalni (KON), integriran (INT), ekološki (EKO) in biodinamični (BD)) in kontrolnih parcelah v poljskem poskusu na posestvu Fakultete za kmetijstvo in biosistemske vede v Pivoli pri Mariboru, Slovenija. Deževnike se je določilo v kolobarju 1 v oktobru 2009 in 2010 z uporabo metode "vroče"gorčične ekstrakcije. Pridelki v BD pridelovalnem sistemu so znašali 99, 113 in 124 odstotkov povprečnih pridelkov vseh PS-jev za pšenico, zelje in bučnice. Tudi AU N, N_{min}, P in K v BD pridelovalnem sistemu pri vseh proučevanih poljščinah v kolobarju 1 je bila v zgornji polovici vseh vključenih PS. Populacija deževnikov in njihova biomasa sta bili signifikantno najvišji in na podobnem nivoju v BD in EKO sistemih pri vseh proučevanih poljščinah, kjer jih je bilo največ najdenih na parcelah z oljnimi bučami. V drugem koraku smo izračunali okoljski odtis PS-jev za pridelavo pšenice in pire in ga interpretirali z uporabo SPionExcel orodja. Tri letni rezultati kažejo znatno manjši okoljski odtis EKO in BD sistema v pridelavi obeh poljščin, najbolj zaradi ne-uporabe zunanjih vnosov. Ko enačbi dodamo pridelke, imata EKO in BD sistem tudi signifikantno manjši skupni odtis na enoto izdelka in višjo okoljsko učinkovitost pridelave. Zato EKO in BD sistema predstavljata uspešni alternativni pri

soočanju z okoljsko degradacijo in klimatskimi spremembami pri pridelavi žit. Kljub temu pa so potrebne izboljšave na področju uporabe kmetijske mehanizacije pri vseh raziskanih sistemih, kot tudi izboljšanje pridelka v EKO sistemu. Prav tako se je povečala pomembnost kakovosti hrane, a ostaja pomanjkanje raziskav na tem področju, vključujoč senzorično kakovost hrane. Zato smo v tretjem koraku raziskali senzorično kakovost belega zelja in rdeče pese v letih 2008 in 2009. Količina pridelkov se ni statistično značilno razlikovala med PS-ji. Skupno je 167 potrošnikov ocenilo štiri lastnosti (barva, vonj, okus in pripravljenost za nakup) z uporabo devet-stopenjske hedonske lestvice. Rezultati kažejo na značilne razlike med PS pri obeh zelenjadnicah; bolje so ocenili vzorce zelja iz INT in kontrolnega obravnavanja napram KON vzorcem (BD in EKO vzorci so bili vmes); BD in kontrolne vzorce rdeče pese so ocenili bolje kot KON in INT vzorce (EKO vzorci so bili vmes). V zadnjem delu smo določili vsebnost sladkorjev, organskih kislin, skupnih fenolov in antioksidativno aktivnost v vzorcih rdeče pese v letu 2009 z uporabo ustaljenih metod. Statistično značilne razlike so bile izmerjene za vsebnost jabolčne kisline, vsebnost skupnih fenolov (TPC) in skupno antioksidativno aktivnost, kjer je bila vsebnost jabolčne kisline med $2,39 \text{ g kg}^{-1} \text{ FW}$ (fresh weight – sveža masa) (kontrola) in $1,63 \text{ g kg}^{-1} \text{ FW}$ (KON, EKO in INT). Najvišji TPC je bil izmerjen v BD in kontrolnih vzorcih ($0,677$ in $0,672 \text{ mg GAE g}^{-1}$), najnižji v KON vzorcih ($0,511 \text{ mg GAE g}^{-1}$). Antioksidativna aktivnost je bila v pozitivni korelaciji s TPC-jem ($r^2=0,6187$) in je znašala od $0,823 \mu\text{M TE g}^{-1} \text{ FW}$ do $1,270 \mu\text{M TE g}^{-1} \text{ FW}$ v KON in BD vzorcih. Skupna vsebnost sladkorjev pa se je gibala med $21,03 \text{ g kg}^{-1} \text{ FW}$ (KON) in $31,58 \text{ g kg}^{-1} \text{ FW}$ (BD). Predstavljena je pomembnost izmerjenih sestavin za človeško zdravje, kot tudi za odpornost in zdravstveno stanje rastlin, in postavljena v perspektivo prihodnosti. BD PS predstavlja uspešno alternativo trenutno prevladujočima KON in INT PS za pridelavo raziskanih kultiviranih rastlin v slovenskem subkontinentalnem zmernem podnebj.

Ključne besede:

biološko-dinamično kmetijstvo; agronomska učinkovitost; deževniki; okoljski odtis; senzorična kakovost; kemijska sestava

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1 Introduction - Biodynamic Agriculture Research Progress and Priorities

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Abstract

Biodynamic (BD) agriculture became the subject of research efforts during the last decades, whereas a part of the scientific community looks at the BD method with skepticism and marks it as dogmatic. Nevertheless, as explored in this review, a fair share of the available peer-reviewed research results of controlled field experiments as well as case studies show effects of BD preparations on yield, soil quality and biodiversity. Moreover, BD preparations express a positive environmental impact in terms of energy use and efficiency. However, the underlying natural science mechanistic principle of BD preparations is still under investigation. In addition, quality determination methods, based on holistic approaches, are increasingly being investigated and recognised. BD farming strives, as manifested in several publications, to positively impact cultural landscape design as well. Summarized data showed that further research is needed and thus encouraged in the field of food quality comparison/determination, food safety, environmental performance (e.g. foot prints), and on the effects of BD farming practices on farm animals.

Keywords:

biodynamic; research; basic experiments; case studies; quality assessment; landscape development

1.1 Introduction

Biodynamic (BD) agriculture, as one of the organic (ORG) agricultural farming methods, was proposed by Steiner (1924) and the BD farming method is striving for diversified, resilient and ever-evolving farms, which could provide ecological, economical and physical longterm sustainability for mankind. It encompasses practices of composting, mixed farming systems with use of animal manures, crop rotations, care for animal welfare, looking at the farm as an organism/entity and local distribution systems (Reganold 1995), all of which contribute towards the protection of the environment, safeguard biodiversity and improve livelihoods of farmers. Nowadays, there are more than 4,200 BD farms in 43 countries, whose area of over 128,000 ha is certified according to Demeter standards (Demeter International e.V. 2009). Next to the standards of ORG agriculture, Demeter standards demand the use of BD preparations, keeping of farm animals, use of animal manures, and strongly encourage local production and distribution systems using local breeds and varieties. Stringent processing standards are in place as well (Demeter International e.V. 2009). The BD method emphasizes a holistic approach towards farming and became the subject of research efforts during the last decades.

However, to what extent can biodynamics be regarded as a scientific category? This review paper will explore and summarize up-to-date peer-reviewed scientific papers, PhD theses and include other sources, where additional information is needed to explain background and modes of action. Basic experiments, case studies, food quality comparisons and landscape design and its development are expected to differentiate between biodynamics and other production systems. Although significant differences were attained with the use of the BD method, the exact mode of action of BD preparations, which present the greatest difference from the ORG production method, remains unexplained. Published research data will be analyzed and future development will be brought into focus to better understand and explain the BD farming method. Finally, research proposals and future implications are put into the wider perspective.

1.2 Basic experiments

Next to published results of short term trials and aimed research (Ryan and Ash 1999; Carpenter-Boggs et al. 2000a; Carpenter-Boggs et al. 2000b; Reeve et al. 2005; Zaller 2007), several longterm trials have been effected with the inclusion of the BD farming method and/or BD preparations (Table 1.1), where all BD preparations, given in Table 1.2, were used.

One of the main features of BD agriculture are BD preparations (Table 1.2). The thoughts behind the preparations are unconventional and sometimes difficult to understand (Reganold 1995) and up-to-date the underlying natural science mechanistic principle of BD preparations is still under investigation, whereas some attempts have been made to explain the mode of action. Effects were firstly explained as a normalization (normalizing yields under low yielding conditions) or compensation (BD preparations compensating for lower N fertilization) effect, where both explanations leave many open questions (Raupp and König 1996). A systems response and adaptation model was suggested as a possible explanation, where the effects of BD preparations do not depend only on their properties and mode of application. Foremost, properties of soils, plants, environmental conditions and how they interact are suggested as factors, which determine the effects of BD preparations to the greatest extent (Raupp and König 1996). Moreover, BD preparations are applied in small quantities of 4 to 160 g/ha, where physical or biological effects seem unlikely (Reganold 1995). However, bioactive ingredients, such as herbicides, have been also found to have great influence in small (less than 10 g/ha) amounts (Zimdahl 1999). In addition, BD preparations were also shown to have hormone-like effects (Goldstein et al. 2004). To better understand the mechanisms behind the BD preparations and to determine ongoing processes in plant physiology, further research designed to separate the effects of the preparations from other aspects of BD farming is needed.

Table 1.1. Main characteristics of long-term trials, which are based on sound scientific methods and include BD research

Country of trial	Trial description	Duration of trial	Size of experimental plots:	Crop rotation and fertilization	References
Therwil, Switzerland	In the DOK trial biodynamic, organic, conventional farm-yard manure and conventional-mineral farming systems are compared to control plots.	1978 - present	10×10 m	Crop rotation same in all systems. 2 fertilizing intensities (0.7 and 1.4 livestock units). FYM ¹ , composted FYM ¹ with added BD ³ preparations and MIN ² are used, depending on production system.	Pfiffner and Maeder 1997; Maeder et al. 2002; Fließbach et al. 2007
Darmstadt, Germany	With the MIN-ORG trial, maintained at the Institute for Biodynamic Research, the question of mineral vs. organic fertilizers is tackled.	1980 - present	5×5 m	Same crop rotation and similar soil tillage is used in all treatments. Nitrogen (N) input levels are maintained at the same level, whereas MIN ² , FYM ¹ and composted FYM ¹ with added BD ³ preparations are used to supply N to the soil.	Raupp 2001
Bonn, Germany	Effects of traditionally composted FYM ¹ against two types of BD ³ composted FYM ¹ and a control plot were investigated.	1993-2001	6×10 m	Same 6-year crop rotation with similar land-management techniques were used. FYM ¹ and composted FYM ¹ with added BD ³ preparations were used as fertilizers at a rate of 30 t/ha.	Zaller and Köpke 2004
Therwil, Switzerland	3-factorial experiment with BD ³ preparations, soil tillage and fertilization as investigated factors	2002-present	12×12 m	Same crop rotation in all treatments. FYM ¹ or slurry are applied to crops at an intensity of 1.4 livestock units.	Berner et al. 2008

¹ FYM – farmyard manure² MIN – mineral fertilizers³ BD – biodynamic**Table 1.2.** Numbers of BD preparations, their main ingredients, mode of use and predicted influence

Number of preparation	Main ingredient*	Use	Mentioned in connection with:
BD 500	Cow manure	Field spray	Soil biological activity
BD 501	Silica	Field spray	Plant resilience
BD 502	Yarrow flowers (<i>Achillea millefolium</i> L.)	Compost preparation/inoculant	K and S processes
BD 503	Chamomile flowers (<i>Matricaria recutita</i> L.)	Compost preparation/inoculant	Ca and K processes
BD 504	Stinging nettle shoots (<i>Urtica dioica</i> L.)	Compost preparation/inoculant	N management
BD 505	Oak bark (<i>Quercus robur</i> L.)	Compost preparation/inoculant	Ca processes
BD 506	Dandelion flowers (<i>Taraxacum officinale</i> Web.)	Compost preparation/inoculant	Si management
BD 507	Valerian extract (<i>Valeriana officinalis</i> L.)	Field spray, Compost preparation/inoculant	P and warmth processes

*The procedure of preparation and fermentation is in detail described by Steiner (1924). BD preparations are designed to be used together on a farm/farming system.

1.2.1 Microorganisms at work

Experimental results show effects of BD preparations not only on yields (Table 1.3), but also on some ongoing processes in compost piles and in the longterm in the soil. Carpenter-Boggs et al. (2000a) report higher average temperatures (3.4°C higher compared to the control pile) throughout the active composting period, whereas Zaller (2007) measured no significant differences in the average temperature of BD and conventional (CON) compost piles. BD treated compost also contained 65% more nitrate in the final samples, respired carbon dioxide (CO₂) at a 10% lower rate and had a larger dehydrogenase enzyme activity to CO₂ production ratio (Carpenter-Boggs et al. 2000a). Carpenter-Boggs et al. (2000a) suggest BD preparations caused these effects through their bioactive ingredients or by serving as microbial inoculants. In addition, the microbial population in BD preparations was found to be substantial (Rupela et al. 2003), where bacteria population ranged from 3.45 to 8.59 log₁₀ g⁻¹. Also a population of fungi was found in the preparations 502 and 506 (5.30 and 4.26 log₁₀ g⁻¹, respectively). Several bacteria and fungi strains showed a potential for suppressing fungal plant pathogens (Rupela et al. 2003). This could also be the reason for the significant and clearcut difference in dehydrogenase, protease and phosphatase activity with respect to the farming systems in the DOK (Biodynamic, Organic and Conventional agriculture longterm comparison) trial, where highest values were measured for the BD system (Maeder et al. 2002). Microbial biomass nitrogen also differed significantly and accounted highest in the BD system with 59% more than in the CON farmyard manure (FYM) system (Fließbach et al. 2007). Furthermore, the microbial biomass carbon was 35% higher in the BD system, compared to the CON-FYM system (Maeder et al. 2002; Oehl et al. 2004). In contrast, Zaller and Köpke (2004) report no differences between treatments in regards to microbial biomass carbon, where untreated FYM and FYM treated with BD preparations were applied (Table 1.4). In both cases microbial biomass carbon was significantly higher than on control plots (Zaller and Köpke 2004), which leads to the conclusion, that FYM had an important effect on the soil microbial biomass buildup. Wada and Toyota (2007) went a step further and discovered that FYM applications add to the stability of soil biological functions, where microbial and fungal populations show resilience and resistance against disinfection.

Table 1.3. Yield comparison of some crops under different agricultural production systems

Table 1a1: Yield comparison of some crops under different agricultural production systems													
Wheat yield			Potato yield			Rye yield			Grass-clover yield			Source:	
Treatments	CON ¹	ORG ²	BD ³	CON ¹	ORG ²	BD ³	CON ¹	ORG ²	BD ³	CON ¹	ORG ²	BD ³	
	110	99	100	154	102	100	n/a	n/a	n/a	125	92	100	Maeder et al. 2002
	n/a	99	100	n/a	101	100	n/a	100	100	n/a	91	100	Zaller and Köpke 2004
	104	99	100	103	94	100	126	94	100	n/a	n/a	n/a	Raupp 2001
	n/a	no difference		n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	n/a	Berner et al. 2008
Average	107	99	100	128.5	97.5	100	126	97	100	125	91.5	100	

Yield relative to BD=100

n/a – no data available

¹ CON - Conventional or mineral treatments² ORG - Organic treatments³ BD - Biodynamic treatments**Table 1.4.** Soil organic matter carbon (C_{org}) change, microbial biomass carbon (C_{mic}) content and dehydrogenase activity depending on the production system

Trial site soil	Sampling depth (cm)	Soil C _{org} beginning (%)	Soil C _{org} change over the trial period (Soil C _{org} beginning =100)			Soil C _{mic} content (CON or MIN= 100)			Dehydrogenase activity (†µg TPF 10g ⁻¹ ; ‡µg TPF g ⁻¹ h ⁻¹)			Source:
			CON ¹ /MIN ²	ORG ³	BD ⁴	CON ¹ /MIN ²	ORG ³	BD ⁴	CON ¹ /MIN ²	ORG ³	BD ⁴	
haplic luvisol	0-20	1.42-1.51	85 / n/a	91	101	100 / 81	117	134	132 / 87 [‡]	175 [‡]	226 [‡]	Fließbach et al. 2007
fluvisol	0-20	n/a	n/a	n/a	n/a	100 / n/a	125	125	88 [†]	130 [†]	130 [†]	Zaller and Köpke 2004 ⁵
Sandy orthic luvisol	0-25	1.05	n/a / 79	91	100	n/a / 100	114	126	75.9 [†]	109.1 [†]	121.9 [†]	Raupp 2001

n/a – no data available /non applicable

¹ CON - Conventional or control treatments² MIN - Mineral treatments³ ORG - Organic treatments⁴ BD - Biodynamic treatments⁵ Estimates are given from figures

†, ‡ attention – results are given in different units

In addition, FYM contributes towards a changed soil nitrogen composition and higher rates of protein amino acids, which bind nitrogen in the soil (Scheller and Raupp 2005). However, differences between treatments do not seem to depend solely on amino acid supply from manure. An altered amino acid metabolism in the soil also influences soil amino acid composition and contents. Soils receiving FYM with BD preparations have a lower catabolism : anabolism ratio than soils receiving non prepared FYM, which results also in a more intensive humification process. The explanation for the influence of BD preparations on anabolism has yet to be found (Scheller and Raupp 2005).

1.2.2 Biodiversity

In this sense, the effects of ORG and BD farming practices are difficult to separate in terms of macro flora and fauna diversity. In the DOK trial, weed species diversity and arthropods (like carabids, spiders and staphilinids) diversity were interrelated and accounted highest in the ORG and BD treatments over the period of 21 years (Maeder et al. 2002), which indicates a good site quality. Fließbach et al. (2007) report a less dense, but more diverse weed flora in BD and ORG plots. Furthermore, BD and ORG treatments affect earthworm species composition (Zaller and Köpke 2004) and quantity (Pfiffner and Maeder 1997; Zaller and Köpke 2004). Significant differences between the BD and ORG treatments are reported for earthworm biomass and quantity in one trial (Pfiffner and Maeder 1997) and species composition and biomass in another trial (Zaller and Köpke 2004).

However, the BD farming method affects the diversity of soil micro flora and fauna more clearly, where various scientists have come to similar conclusions on the basis of long term trials. When looking at the complexity and diversity of the microbial food web in soils, the metabolic quotient for CO₂ ($q\text{CO}_2$) indicates the economy of microbial carbon utilization (Anderson and Domsch 1993). Higher $q\text{CO}_2$ values can indicate young microbial communities with greater energy requirements to maintain itself, whereas lower $q\text{CO}_2$ values, which were also found for long-term (more than 8 years) cultivated BD soils, indicate less stressed soils and thus diverse and highly interrelated soil communities (Goldstein et al. 2004; Zaller and Köpke 2004; Oehl et al. 2004; Scheller and Raupp 2005; Fließbach et al. 2007). In line with these findings, Carpenter-Boggs et al. (2000b)

measured higher $q\text{CO}_2$ values for soils amended with BD compost in a 2 year short-term study.

1.2.3 Environmental impacts

Soil organic matter is an important indicator of the soil organic carbon pool in soils. Increasing the amount of carbon stored in vegetation and soil (also called carbon sequestration) is a preventative measure towards slowing carbon dioxide (CO_2) buildup in the atmosphere (Janzen 2004). Soil organic carbon was maintained at the same level for over 21 years and even showed a small gain in the BD system at the DOK trial, whereas the other farming systems investigated all had a net loss of soil organic carbon (Fließbach et al. 2007). Similarly, soil organic matter in the MIN-ORG (Mineral vs. Organic fertilization) trial was maintained at the same level only in the BD, whereas it declined in the FYM and mineral treatments (Raupp 2001; Scheller and Raupp 2005). Farm scale comparisons also show differences between conventional and BD farms, where longterm BD cultivation results in higher soil organic matter levels (Reganold et al. 1993; Droogers and Bouma 1996). Next to CO_2 and methane, also nitrogen in the form of nitrous oxide plays an important role in greenhouse gas emissions from agricultural land use (Janzen 2007). With the rising use of supplemental nitrogen added to soils, also nitrous oxide emissions increase and might become a more urgent issue in tackling greenhouse gas emissions from agriculture than CO_2 is today (Janzen 2007). When we look at the DOK trial, the ratio between yield levels and nitrogen applied turns out highest in the BD and ORG systems, when compared to the conventional and minerally fertilized systems and ranges from 2:1, 2:1, 1:1 to 1:1.2, respectively (Maeder et al. 2002), indicating more efficient use of the nitrogen supplied in BD and ORG systems. Moreover, the BD system contained higher levels of total soil nitrogen on the account of soil organic matter and soil microbial biomass when compared to the other systems investigated (Fließbach et al. 2007).

In addition, rising energy prices will eventually intensify interest in the search for farming systems, where energy efficiency would consistently increase and consequently energy consumption per unit will be lower (Pimentel et al. 2005). However, interest is already

present, as longterm studies and farm comparisons have been carried out comparing energy efficiency of different farming systems. Results show better performance of ORG systems (Pimentel et al. 2005), as well as the BD system (Maeder et al. 2002). As mentioned before, yields are lower in the BD system (compared to the CON-FYM system), but so is the energy consumption up to 50% lower mainly due to non-use of external production factors, like mineral fertilizers and pesticides (Maeder et al. 2002). This leads to a more energy efficient production in the BD system (20-56% better than CON-FYM), in terms of energy consumption per crop unit of dry matter and energy consumption per unit of land area (Maeder et al. 2002). Less fossil energy used results in less carbon dioxide being emitted to the atmosphere and thus has a direct impact on global climate change mitigation (Janzen 2004).

1.3 Case studies of production systems

The first peer-reviewed study directly comparing BD and CON farms was carried out in New Zealand on 16 farms (Reganold et al. 1993). BD farming practices for at least 8 years resulted in higher soil organic matter contents, increased quality of soil structure, increased microbial activity and higher numbers of earthworms. BD farms were financially as viable as their CON counterparts.

Droogers and Bouma (1996) compared BD and CON soils on two neighbouring farms, where each farming practice has been applied for at least 70 years. They found significant differences in SOM content and water availability in favour of BD soils. In addition, soil density and thus compaction was lower in BD soils. Initial research provided data for a simulation model, in which BD farming practices expressed higher yield potential, longterm stability and sustainability than CON soils.

Several comparisons between BD and CON farms have been effected in Australia, where the main focus was on phosphorus (P) availability in relation to arbuscular mycorrhizal fungi, since P is a limiting nutrient in Australian soils (Ryan and Ash 1999). According to Ryan et al. (2000), there is a strong negative correlation between the levels of P (soil extractable and in pasture shoots) and arbuscular mycorrhizal fungi colonisation in white

clover and rye grass, where BD plants and soils contain less extractable P, but have higher levels of arbuscular mycorrhizal fungi colonisation. Also, a steady decline of arbuscular mycorrhizal fungi in 2 out of 3 CON farms was observed. However, it is suggested that higher arbuscular mycorrhizal fungi colonisation can not compensate for the lower levels of soil extractable P in the final yields of BD systems. It is discussed that nutrient mobilization from soil minerals is not the only benefit of arbuscular mycorrhizal fungi. Frey-Klett et al. (2007) report that fixation of atmospheric nitrogen and protection of plants against root pathogens are also among the myriad benefits of arbuscular mycorrhizal fungi and mycorrhiza helper bacteria. Raupp (2001) also reports a higher density of roots on plots treated with BD preparations. Mycorrhiza helper bacteria could be the possible reason for this effect, as they have been proved to stimulate lateral root formation and thus increase potential root-mycorrhiza interaction points (Frey-Klett et al. 2007).

Burkitt et al. (2007a) compared 10 BD and CON dairy farms for 4 years in northern Victoria and New South Wales. In some points, findings are comparable to results of longterm systems trials done in Europe, where soil P has a negative balance. The N and K balance, however, are reported to be non-significantly different between BD and CON farms. Soil organic carbon and soil microbial biomass are also reported to be equal between the farming systems. In addition, earthworm biomass was greater in the CON system on account of one earthworm species, where no information was given on the number of earthworms. Burkitt et al. (2007b) also report lower milk yields on BD farms on a per hectare and per cow basis. A significantly greater number of chemical treatments per cow were used on CON farms. However, this did not result in reduced parasitic infection, for infection levels were similar on both farm types. In addition, somatic cell count was higher on farms under BD management, where, in turn, also significantly less chemical treatments were used. Information on incidences of clinical mastitis and longevity of animals, however, is not provided. Burkitt et al. (2007b) suggested the use of certified inputs on BD farms to increase milk fat, protein and production levels, but did not give further details. This was the only published study found which dealt with farm animals and BD farming practices, thus a serious lack of research projects/results is found and research in this area is strongly encouraged.

The difference between Australian BD farms reported in studies and other BD field trial comparison studies and farm comparisons is, however, that in Australia only preparation BD 500 was applied 1-2 times each year (Ryan and Ash 1999). Also Nguyen and Haynes (1995) report only preparation BD 500 being used on a BD farm in New Zealand. As discussed in professional literature, however, the preparations were designed to be used together and only as such they can have the desired effectiveness. In addition, because of all year grazing farming systems, Ryan and Ash (1999) report no additional organic fertilizers added to soils for over 17 years. Nguyen and Haynes (1995) also report no organic or inorganic fertilizers being used on BD soils and as a consequence also lower yields in a 4 year crop rotation (without pastures). In addition, results of previous studies were confirmed which indicate BD farming systems as more energy efficient (both in terms of crops and animals) on a per hectare basis but at the same time also more labour intensive than conventional farms (Nguyen and Haynes 1995).

BD wine grape production is also increasingly attracting attention, as some of the world's prestigious wine producers have started to use BD practices in the last decade (Reeve et al. 2005). Research followed suit and experimental results suggest BD practices have an effect on wine grape canopy and chemistry, whereas no significant effects on soil fertility parameters were shown in a 6 year on farm comparison trial between ORG and BD practices in an organic vineyard in California (Reeve et al. 2005). Probst et al. (2008), however, measured significant differences in soil fertility between CON and BD soils on farms with a long history of BD (since 1981) and CON cultivation. Results are in accordance with findings stated in Table 1.4. More research is needed to make conclusive statements on quality performance and a long-term systems comparison trial in wine grape production would be of great scientific and practical value.

1.4 Quality assessment

Bio-crystallization and the capillary dynamalysis (or Steigbild) method are two so called picture forming or holistic methods to assess food quality and origin. Although originating in the 1930's it is in recent years that they are gaining more attention as innovative quality concepts (Kahl 2006), not only in connection with BD, but also with ORG agriculture. The

methods have been developed from the viewpoint that living organisms do not just exist as substances, but have structuring and organizing properties (ie. one can know the exact composition and quantity of elements an apple has, but still can not “produce” an apple by mixing those substances). These properties control the form and function of an organism (Meelursarn 2006). At first, soluble extracts of the desired food product are prepared according to the defined working standards of each method, which have been up-to-date validated and tested on several samples originating from controlled field system comparisons (Kahl 2006). Furthermore, a Triangle network of laboratories dealing with bio-crystallization (University of Kassel, Louis Bolk Instituut and Biodynamic Research Association Denmark) was established, whose goal is to develop uniform ISO standards for the evaluation of biocrystallograms and dynamalysis pictures (Andersen et al. 2003). Next to the introduction of computer image analysis (Andersen et al. 1999), a modified method of panel evaluation of obtained images, using a defined set of 10 criterion, was tested and successfully applied (Kahl 2006). With the use of these methods, however, up-to-date one is able to discriminate only products originating from controlled field trials with different production methods, and thus create reference lines. Plants grown in different climatic and environmental conditions express different qualitative parameters and therefore one is unable to make direct comparisons and conclusive statements on the quality of such plants, which is also true for sensory evaluation methods. Recent promising results from renowned institutions and an increasing number of dissertations in the last years could spur even more interest and acceptance of picture forming quality determination methods.

1.5 Landscape development in relation to biodynamics

The idea of a farm organism or farm individuality is one of the core principles of BD agriculture (Steiner 1924). Usually it indicates that farm management should minimise nutrient and energy inputs in order to make the farm self-supporting and autonomous (Vereijken et al. 1997), which is true also for ORG farms. But it also encompasses a broader idea of the farm placement in its surroundings, the involvement of the people working on the farm, a balance between the sub-systems or “organs” of the farm (arable

crops, pastures, livestock, horticulture, ...) and the elements of nature, such as forests, heaths, moors and watercourses (Vereijken et al. 1997). In addition, Ho and Ulanowicz (2005) provide supportive arguments for an organisms point of view upon sustainable systems, based on thermodynamics. If we extend this point of view to a greater scale, a farm also plays an important role in landscape design and development. For this reason, a bottom-up, present situation improvement approach towards landscape design on farms has been developed, where it is aimed to develop nature compliant agricultural systems, starting with the acceptance of the natural conditions and developing them according to the needs of the society (Beismann 1997; Vereijken et al. 1997). The Goethean-phenomenological approach has, next to CON methods and solutions, an integral part in this method of landscape assessment, design and development (Colquhoun 1997). In conjunction with the above mentioned methods this bottom-up approach resembles participatory action research, where researchers are not merely observers of the system, but actively take part in the process of shaping it (Greenwood et al. 1993). Moreover, it is argued that sustainable and ecologically sound management of the landscape cannot be achieved only by top-down planning and regulations, but rather with bottom-up, individual and participatory landscape development (Beismann 1997). Indeed, solutions to problems of one farm do not necessarily solve the same type of problem on another farm and tailor made solutions should be applied, where demanded (Vereijken et al. 1997). Encompassing a broader set of goals than just landscape design, Helmfrid et al. (2008) used participatory action research methods to research and shape local, sustainable and environmentally friendly food systems. Linking both approaches with a goal of improving agricultural and natural systems is a promising future perspective.

1.6 Conclusion

Many questions on BD farming practices have been addressed in the last decades and results were published in more than 30 peer reviewed scientific papers. We have a better understanding of the effects of BD farming on soil physical, chemical and biological properties, crop growth, yield, processes in soils, etc. BD farming practices are also gaining importance in the face of increasing climate change, energy scarcity and

population growth, where they indicate a more resilient, diverse and efficient system. In this sense BD farming presents a viable farming method, which is worthy of study in more detail on its own account. But what are the priorities in moving forward? Is getting a deeper understanding of the exact mode of action of BD preparations one of them? Until now no fully satisfactory natural science mechanistic principles explanation has been provided. However, the systems response and adaptation model (Raupp and König 1996) does give a partial, however promising, explanation. But still, does this lack of clarity make the BD method unscientific? There is also not a satisfactory explanation on the pathways and mechanisms of soil organic matter equilibrium establishment in soils (Stevenson 1994), but the topic is still considered to be of high research interest to scientists. So in order to better understand the role and effects of BD preparations, some methods as photosynthesis measurements and isotope marking could also be taken into consideration. It is important to search for inspiration in the “Agricultural course” (Steiner 1924), but also make a step ahead and develop new ideas, research current challenges we are faced with (Turinek et al. 2008) and build new, yet undiscovered perspectives of BD agriculture, while taking into account over 80 years experience (Koepf et al. 1996) with the BD method.

What about energy efficiency on a wider scale (production to consumption)? Does it make a difference if the preparations are made on-farm or bought from a distant location? Does this affect the effectiveness of the preparations? Must the making of the preparations with the use of animal organs stay as given by Steiner (1924)? Or do we need to move forward, explore new possibilities and develop an understanding for the reasons behind given procedures? This is especially an important issue in the face of recent stringent EU hygiene and sanitary regulations (EC 1774/2002), which were put in place because of animal diseases that originated in industrial farming. What about research on farm animals? Moreover, is there a difference between BD prepared compost of animal and plant origin? How does this affect soil fertility and health? And after all, do we need to make more production systems comparison trials? If yes, how well defined are the systems to be compared? And what are the areas of interest to compare? Food quality is certainly a still highly discussed and debated area, which would deserve more attention on this account.

A working group of researchers and professionals, who gathered in an active process to exchange thoughts, experiences and research results (Hurter 2007), is certainly a way-sign into the future. Also a web portal on biodynamic research (Biodynamic-Research-Team 2009), which was recently put into practical existence, could facilitate the exchange of ideas, thoughts and results. A worldwide network of farmers, researchers, advisors, teachers and others interested in BD farming could contribute towards naming and addressing questions from everyday practice in order to make important steps towards a more sustainable, healthy, prosperous and secure future.

1.7 Reviewers response

At the Editor's suggestion we are including a reviewers perspective in order to broaden the understanding of the subject matter:

“My personal perspective is that the authors do not need to ask whether BD can be regarded as a scientific category or even point out that part of the scientific community looks at it with skepticism and marks it as dogmatic. There are over 4200 farms around the world that are certified as BD so it is clearly worthy of study. There are also many research studies and publications identifying the benefits of organic farming and the ability to maintain yields and improve soil health with organic farming methods. To my knowledge BD includes all the key components of ORG so what is true for ORG is true for BD.”

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2 Yields, agronomic efficiency and earthworm populations in the biodynamic farming system for wheat, cabbage and oil pumpkin seed production

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Abstract

Biodynamic (BD) agriculture has substantially influenced the development of alternative agricultural systems in the past. However, yields, agronomic efficiency (AE) in relation to yields in some crops and the earthworm populations depending on those crops remain to be explored under the BD production system. Therefore, wheat, cabbage and oil pumpkins were produced over three successive years (2008–2010) under four production systems (conventional, integrated, organic and BD) with control plots in a field trial near Maribor, Slovenia. Earthworms were determined in October 2009 and 2010 using the “hot” mustard-extraction method. Yields in the BD production system amounted to 99, 113 and 124 per cent of the average yields of all production systems for wheat, cabbage and oil pumpkin seeds, respectively. Additionally, the AE of the N, N_{min}, P and K of the BD system for the production of all crops studied was in the upper half of all production systems under investigation. Moreover, earthworm populations and biomass were highest and on a similar level in the BD and organic systems in all three crops investigated, where most were found in the oil pumpkin plots. Thus, the BD production system presents a viable alternative to the current predominant conventional and integrated production systems for the production of wheat, cabbage and oil pumpkins under the Slovene sub-continental temperate climate.

Key words:

organic agriculture; biodynamic agriculture; integrated agriculture; earthworm populations; earthworm biomass; farming system comparison

2.1 Introduction

Biodynamic (BD) agriculture has substantially influenced the development of alternative agricultural systems in the past, from the core idea of a farm as an organism to the nutrient and energy cycling principles that are innate to modern organic farming (Turinek et al. 2009). However, some questions remain open regarding the agronomic efficiency of this more than 80-year-old approach towards sustainable farming.

Yields and the agronomic performance were researched in some field-comparison trials in Switzerland and Germany (Raupp 2001; Maeder et al. 2002; Zaller and Köpke 2004; Berner et al. 2008). Yield levels were found to be 5 to 28 per cent lower in the BD compared to the conventional (CON) system for wheat, potato, rye and grass-clover crops (Turinek et al. 2009). However, the ratio between yield levels and N applied turned out to be highest in the BD and organic (ORG) systems in one trial, when compared to the CON and minerally fertilized systems and ranged from 2:1, 2:1, 1:1 to 1:1.2, respectively (Maeder et al. 2002). This comparison does, however, give only a non-detailed broad perspective and lacks a comparison of the differences regarding other nutrients. Moreover, the BD system performed best regarding the levels of total soil N when compared to the other systems, where great amounts of N were denitrified into the atmosphere but were retained in the BD system in the form of soil organic matter and soil microbial biomass (Fließbach et al. 2007).

The BD and ORG systems also exerted an influence on the composition and number of earthworms in two trials in one season and crop (Pfiffner and Maeder 1997; Zaller and Köpke 2004). In contrast, Burkitt et al. (2007) found no differences in the number or composition of earthworms between CON- and BD-managed fields on 10 farms in Australia.

Thus, yields, agronomic efficiency (AE) in relation to yields in some crops and the earthworm populations depending on the production system and crop remain to be explored. Consequently, the aims of this study were to: 1) produce crops (winter wheat (*Triticum aestivum* L.), white cabbage (*Brassica oleracea* var. *capitata* L.) and oil pumpkins (*Cucurbita pepo* var. *styriaca* L.)) in a crop rotation using different production

systems under the Slovene sub-continental temperate climate; 2) measure applied nutrients and yields in three successive years and earthworm populations and biomass in two successive years for those three crops; and 3) analyse the data collected and compare the production systems.

2.2 Materials and methods

2.2.1 Long-term field trial

The experimental site for the production of the crops was 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 yearly mean air temperature of the area is 10.7 °C, where the mean monthly minimum occurs in January at 0.4 °C, and the average monthly maximum is in July at 20.8 °C. The average annual rainfall in the area is around 1000 mm. Sixty 7 m × 10 m experimental field plots were established in 2007 on a dystic cambisol (deep) and were maintained within two different five-course crop-rotation designs, where various sequences of crops in the crop rotations were used. In one rotation, there were typical crops for this region (two years of red-clover grass, winter wheat, white cabbage and oil pumpkins); the other one was an alternative crop rotation (two years of red-clover grass mixture, spelt, red beet and false flax). Four production systems (CON, integrated (INT), ORG, BD) and control plots (no fertilization or plant protection) were arranged in a randomized, complete-block split-plot design with four replicates. 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 six years before the trial started in 2007. Soil cultivation, sowing and harvesting were identical among experimental plots and were performed on similar dates and in a similar manner to adjacent fields. The farming systems differed mostly in plant protection and fertilization strategies, and they were managed in accordance with the laws and rules defining each farming system (MKGP 2002, 2004, 2006, 2008; EC 834/2007 2007; Demeter International e.V. 2009). The reader is kindly referred to previously published publications (Bavec et al. 2010) for a detailed description of differences between farming systems.

Additionally, the same varieties were used in all farming systems under study (winter wheat 'Antonius', white cabbage 'Kranjsko okroglo' and oil pumpkin 'Gleisdorfer Ölkürbis'), of conventional origin for CON and INT systems and of organic origin for ORG, BD and control systems.

2.2.2 Agronomic efficiency of applied nutrients

Roberts (2008) argues that agronomic nutrient-use efficiency presents the basis for economic and environmental efficiency in agricultural production. Which indicator to use in describing nutrient-use efficiency also greatly depends on the available resources and the focus of the research. However, AE, defined as crop yield increase per kg nutrient applied, is regarded as a good and comparable indicator of nutrient-use efficiency (Ladha et al. 2005).

Fertilisers applied were either analysed for their content of N, N_{min}, P and K in each year separately (ORG and BD systems) or the amount of NPK was given on the accompanying product-specification labels (CON and INT systems). In the first year, no BD compost was available; thus, rotted farmyard manure (FYM) was applied in both the ORG and BD systems. The amounts of NPK nutrients applied each year are presented in Table 2.1.

The AE of applied NPK nutrients was calculated according to Ladha et al. (2005) using the following equation:

$$AE_{(\text{Nutrient})} = \Delta Y / F_{(\text{Nutrient})} \text{ in kg kg}^{-1} \quad (2.1)$$

where ΔY is the yield difference between the production system under question and the control plot in each year and $F_{(\text{Nutrient})}$ is the amount of a nutrient (N, N_{min}, P or K) applied in the same plot and year. This was done for each crop, year and plot separately and, subsequently, it was statistically evaluated.

Table 2.1. Amount of nutrients (NPK) applied in wheat, white cabbage and oil pumpkin production in the years 2008, 2009 and 2010 (in kg ha⁻¹)

Wheat	2008			2009			2010		
	N	P	K	N	P	K	N	P	K
Production system									
Conventional	208	80	120	208	80	120	208	80	120
Integrated	170	30	105	120	30	105	150	30	105
Organic ¹	107	27	55	106	36	162	81	29	125
Biodynamic ¹	107	27	55	112	57	45	90	32	37
Control plots	0	0	0	0	0	0	0	0	0
Cabbage									
Conventional	143	70	300	155	70	300	145	70	300
Integrated	153	30	300	165	30	300	150	30	300
Organic ¹	107	27	55	106	36	162	81	29	125
Biodynamic ¹	107	27	55	112	57	45	90	32	37
Control plots	0	0	0	0	0	0	0	0	0
Oil pumpkins									
Conventional	125	130	180	125	130	180	125	130	180
Integrated	123	83	98	123	83	98	123	83	98
Organic ¹	107	27	55	106	36	162	81	29	125
Biodynamic ¹	107	27	55	112	57	45	90	32	37
Control plots	0	0	0	0	0	0	0	0	0

N – nitrogen; P – phosphorus; K – potassium; ¹ – cattle manure and composted cattle manure added in organic and biodynamic farming, respectively, were analysed for their content of NPK before application each year

2.2.3 Earthworm sampling

Earthworms were sampled in October 2009 and October 2010 according to a modified “hot” mustard-water extraction method (Lawrence and Bowers 2002) combined with hand digging. To achieve this, we pressed a 50 cm × 50 cm metal frame about 10 cm into the soil and filled it with 15 litres of tap water containing 150 g of mustard solution (1 part of finely ground mustard seeds cv. ‘Zlata’ with 2 parts of water, mixed for 2 hours prior to

sampling and afterwards stored in an air-tight container). All earthworms appearing on the surface of the sampling area within 20 min were collected, then the whole sampling area was hand dug to a depth of 10 cm. Any additional earthworms found were placed with the others, weighed, counted and assigned to one of three ecological groups (epigeic, endogeic or anecic (Bouché 1977)). Epigeic earthworm species live in or near the surface litter-feeding primarily on coarse particulate organic matter. Endogeic species live within the soil profile and predominantly feed on soil and associated organic matter, whereas anecic species live in vertical burrow systems and are believed to feed primarily on surface litter which they pull into their burrows (Bouché 1977; Edwards and Bohlen 1996).

2.2.4 Statistical analysis

Data for the yields, AE, and earthworm populations and biomass were analysed by a multifactor ANOVA, with production system and year as factors, using Statgraphics Centurion (Version XV, StatPoint Technologies, Inc., Warrenton, VA). This was followed by least-squares mean comparisons after Duncan (Hoshmand 2006).

2.3 Results and discussion

2.3.1 Yields

Yields of wheat (given at 14 percent moisture in grain) varied among production systems and years (Table 2.2), whereas there was no significant interaction of both factors under consideration. Highest yields of wheat were attained in the CON production system (4,263 kg ha⁻¹), and the lowest in the control and ORG production systems (2,467 and 2,450 kg ha⁻¹, respectively). Average CON yields are in accordance with the average attained yields for wheat in Slovenia in recent years (SURS 2009), whereas ORG wheat yields are relatively low, when we take into account the nutrient input into the farming system each year (Table 2.1). However, the BD and INT systems performed closer to the average of all farming systems, and thus point to more balanced yields. Reasons for a relatively high difference between the ORG and BD systems could be due to the use of compost instead of rotted FYM in the BD system and/or the use of BD preparations, which have been found to

improve fertility of soils and nitrate availability in compost in previous studies (Turinek et al. 2009). Timely N mineralisation in soils seems to have played an important role in providing crops with sufficient nutrients and, consequently, resulted in higher yields (Ladha et al. 2005), as these crops were stimulated with higher average temperatures in April 2009 and subsequent sufficient availability of moisture in May and June 2009, when the wheat plants require most N (Olk et al. 1998).

Table 2.2. Yields of wheat, cabbage and oil pumpkin seeds depending on production system and year

Factor	Wheat		Cabbage		Oil pumpkin seeds	
	Yield (kg ha ⁻¹)	Relative yield ¹ (%)	DM yield (kg ha ⁻¹)	Relative yield ¹ (%)	Yield (kg ha ⁻¹)	Relative yield ¹ (%)
Production system (PS)						
Control	2,467 ± 207c	77	1,729 ± 339	84	414 ± 71	98
Conventional	4,263 ± 469a	133	1,995 ± 148	97	333 ± 75	79
Integrated	3,683 ± 451ab	115	1,949 ± 207	94	453 ± 96	107
Organic	2,450 ± 263c	76	2,307 ± 389	112	386 ± 58	91
Biodynamic	3,136 ± 305bc	99	2,338 ± 309	113	524 ± 101	124
Year (Y)						
2008	2,530 ± 134b	79	2,519 ± 270a	122	358 ± 58	85
2009	3,882 ± 431a	121	2,216 ± 131a	107	496 ± 41	118
2010	3,186 ± 212ab	100	1,456 ± 159b	71	411 ± 82	97
Average	3,200	100	2,064	100	422	100
ANOVA						
PS	***		n.s.		n.s.	
Y	***		***		n.s.	
PS × Y	n.s.		*		n.s.	

¹ average value of each factor = 100%

Mean values ± standard errors are presented. Different letters indicate statistically significant differences at 95% probability (Duncan test). Levels of significance: n.s. - non-significant ($p > 0.05$); * ≤ 0.05 ; *** ≤ 0.001

Cabbage was produced and harvested across three successive seasons in four different production systems and a control treatment. Yields (on a fresh weight as well as on a dry-matter (DM) basis) varied significantly amongst the years but not amongst the production systems (Table 2.2) and amounted to the average marketable yields under Slovenian conditions (SURS 2009). Despite this, notable differences between the average marketable

DM yields of the various production systems exist, where the highest yields for cabbage were attained in the alternative ORG and BD production systems, followed by INT, CON and the control plots. Nutrient availability through soil organic matter seems to have exerted itself positively on cabbage yields, as the ORG and BD systems received a substantial amount through the added FYM and compost, respectively. However, the diminishing soil-building effect of the clover-grass crop (Lampkin 2002) is visible in the significant interaction of production systems and years (data not shown), where all systems (except the CON system) show a tendency for lower yields from 2008 towards 2010, although lower yields in 2010 could also have been influenced by lower precipitation in the months of crop establishment (Figure 2.1).

Oil pumpkin seed yields (given at 9 percent moisture in grain) did not significantly differ amongst years and/or production systems (Table 2.2). Average yields were on the same level as found in a previous study on this area (Jakop 2010) and those reported elsewhere in the literature (Bavec and Bavec 2006). It is, however, interesting that the influence of production systems, most importantly the differing fertilisation, did not have a significant effect on the yield of pumpkin seeds. Even more notable was the fact that the INT and BD systems, where the average amount of applied nutrients was lower as compared to the CON and ORG systems, had higher average yields than their counterparts, respectively. The interaction of factors on the level of soil–plant–soil flora and fauna–air conditions–temperature is highly complex and sometimes small differences between treatments trigger greater consequences in the form of a snowball effect (Heinze et al. 2010). Differing production conditions in the three years in the form of a changed rainfall and temperature curve (Figures 2.1 and 2.2) seem to have played an equal role on yields of pumpkin seeds, just as fertilisation and plant protection management did. Oil pumpkins, as a crop for a warm climate, are known to be sensitive to temperature fluctuations in the early establishment phase (especially to temperatures lower than 10 °C) (Bavec et al. 2002), which was the case in the year 2008 and 2010, when in May and June days with temperatures lower than 8 °C occurred. This was partly compensated for in 2010 with high average temperatures in July. Furthermore, yield reductions can also be expected in the case of limited moisture (Bavec and Bavec 2006), which occurred in the early developmental stages (May–July) of 2010.

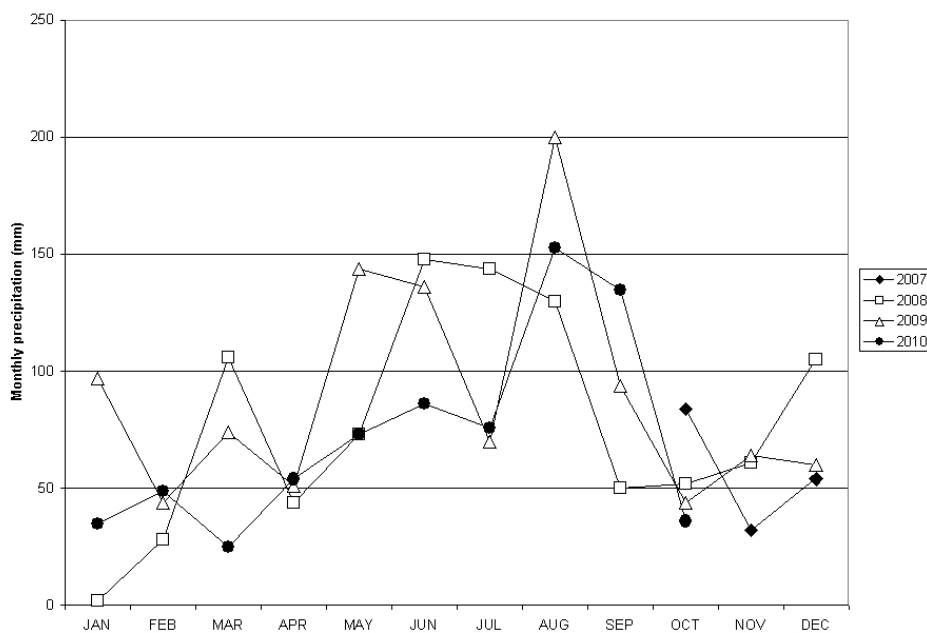


Figure 2.1. Monthly precipitation for the duration of the trial (October 2007–October 2010)

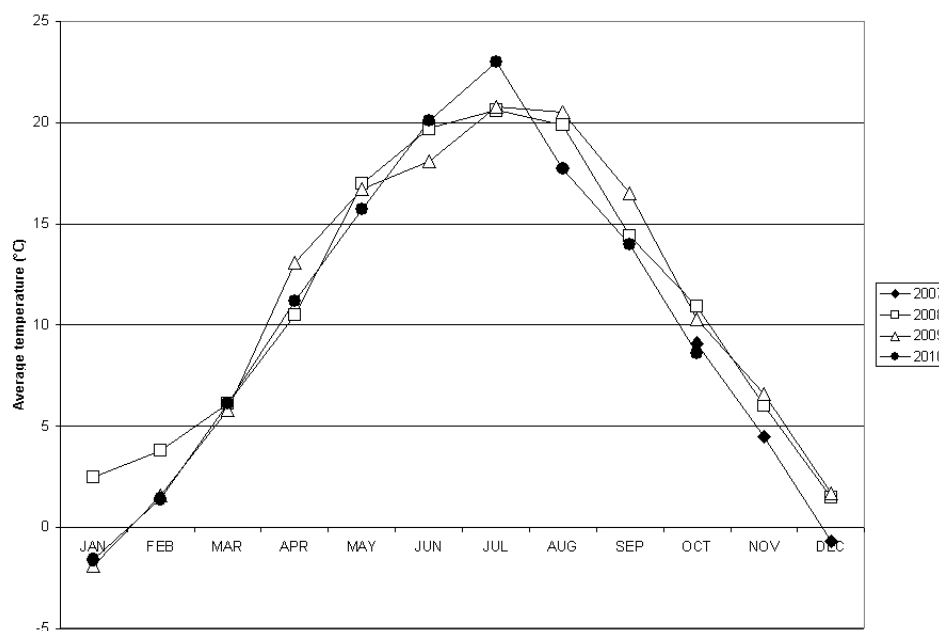


Figure 2.2. Average monthly temperatures for the duration of the trial (October 2007–October 2010)

2.3.2 Agronomic efficiency of applied nutrients

The AE of applied N fertilisers varied significantly among production systems (for wheat and cabbage) and years (all three studied crops) (Table 2.3). However, there is no general rule observable as to which production system had better AE, as N availability and use efficiency depends directly and indirectly on numerous factors, where soil water, organic matter content, soil temperature and aeration and N demand by crops are among the more important ones (Ladha et al. 2005).

Modern wheat varieties, which have been bred to utilise applied ammoniacal N fertilisers to as great an extent as possible (Mulvaney et al. 2009), also react positively to such applications in our trial, where the INT and CON systems have the highest AE(N) and where N demand is most closely matched with N supply through three split applications of ammoniacal N. However, the BD system, where only one application of compost was made in autumn, is also in the same class as the industrial systems (Table 2.3). Nitrate availability in BD-treated compost and a changed amino-acid metabolism through the application of BD preparations and, thus, higher N use efficiency as previously found (Carpenter-Boggs et al. 2000a; Maeder et al. 2002; Turinek et al. 2009) could also explain the high AE(N_{min}) values for the BD system in wheat and oil pumpkin seed production. From a broad perspective, the AE of wheat is rather low when compared to other fertilization studies (Ladha et al. 2005), probably because of the N supply from biological nitrogen fixation (Mulvaney et al. 2009) through two years of the clover-grass ley preceding the main crops and, thus, this led to relatively high yields in the control plots and somewhat distorted yields in all other systems. This could also hold true for the AE(N) in cabbage and oil pumpkin seed production. Furthermore, Mulvaney et al. (2009) argue that a long-term supply of mineral N depletes the total N pool in soils (and, in turn, also lowers the total organic matter content) and thus leads to stagnating or declining yields in grain production, although inputs of mineral N have continued to rise over the last few decades. Mulvaney et al. (2009) urge that there is a change needed in agricultural practice and a shift from intensive synthetic N inputs towards agricultural diversification including legume-based crop rotations.

Table 2.3. Agronomic efficiency (AE) of added N, N_{min}, P and K nutrients depending on production system and year for wheat, cabbage and oil pumpkin seed production

Factor	Wheat				Cabbage (on a dry-matter basis)				Oil pumpkin seeds			
	AE (N)	AE (N _{min})	AE (P)	AE (K)	AE (N)	AE (N _{min})	AE (P)	AE (K)	AE (N)	AE (N _{min})	AE (P)	AE (K)
Production system (PS)												
Control	0.0b	0.0b	0.0c	0.0b	0.0b	0.0b	0.0c	0.0b	0.0	0.0	0.0	0.0
Conventional	8.8a	8.8b	22.4ab	15.0a	2.0ab	2.0b	3.8bc	0.8b	-6.6	-6.6	-6.2	-4.5
Integrated	9.2a	9.2b	40.3a	11.6a	1.6ab	1.6b	7.3abc	0.7b	3.2	3.2	4.7	4.0
Organic	-0.2b	8.0b	0.0c	0.8b	5.9a	170.7a	21.4a	9.2a	-1.8	-1.1	-8.8	-4.8
Biodynamic	6.3a	125.9a	17.9bc	14.6a	6.0a	138.3a	19.2ab	13.6a	13.1	317.8	38.1	32.2
Year (Y)												
2008	3.2b	44.9	13.2	5.7b	3.7a	108.7a	15.3a	7.6	-0.6	-58.0b	-6.0b	-1.9b
2009	7.9a	23.6	24.5	13.2a	-0.1b	4.0b	-1.5b	0.9	-6.0	-32.3b	-10.7b	-7.6b
2010	3.5b	22.7	10.7	6.3b	5.7a	74.8ab	17.3a	6.0	11.3	278.2a	33.4a	25.6a
ANOVA												
PS	***	*	***	***	*	***	*	***	n.s.	n.s.	n.s.	n.s.
Y	*	n.s.	n.s.	*	**	*	**	n.s.	n.s.	*	*	*
PS × Y	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	*	n.s.	n.s.	*	*	**

Mean values are presented. Different letters indicate statistically significant differences at 95% probability (Duncan test). Levels of significance: n.s. - non-significant ($p > 0.05$); * ≤ 0.05 ; ** ≤ 0.01 ; *** ≤ 0.001

AE(P) values are not as much influenced by year of production, as by production system (Table 2.3). Soil-soluble P present in soils prior to the beginning of the trial was above average levels (0.278 g kg^{-1}); thus, fertilisation in the INT system was adjusted accordingly, with only half of the standard ratio. This resulted in an improved AE(P) of the INT system; however, differences were pronounced and significantly different only for wheat production, and not for the other two crops. This is likely also a consequence of the plant–soil interactions, where plants actively mobilise nutrients from the soil through root exudates, which in turn mobilise the soil flora and fauna to supply the needed nutrients (Badri and Vivanco 2009).

Similarly to P and N, AE(K) also depends on the year of production (wheat and oil pumpkins) as well as on the production system (wheat and cabbage), where similar mechanisms of plant–soil interactions, as well as environmental factors (water, air, solar radiation) come into play. It is also interesting to observe that the AE of oil pumpkin seed production was not significantly influenced by the production systems. However, it was influenced by the year of production. Probably a relatively high supply of nutrients from the preceding white cabbage crop (George and Eghbal 2003) and the remains of the grass-clover crop were the main cause for this effect. Nevertheless, there was a trend of a higher AE of the BD system in oil pumpkin production, which could be explained by a more diverse and stable microbial community through the added BD compost (Carpenter-Boggs et al. 2000b; Zaller 2007; Fließbach et al. 2007) and thus a more stable nutrient supply throughout the season.

2.3.3 Earthworm populations and biomass

Earthworms were sampled in autumn in two successive years after the harvest of the main crop had been accomplished on all plots in the trial. Earthworm species appearing under temperate climates in central Europe either have a life-cycle peak or are in a productive life stage in autumn (Bouché 1977; Edwards and Bohlen 1996).

Significant differences between production systems appeared for the quantity of epigeic earthworms, where more were found on ORG and BD plots for all crops (Table 2.4).

Table 2.4. Earthworm count (by categories) and total mass (in grams) in 2009 and 2010 depending on production system and year for wheat, cabbage and oil pumpkins production sampled on an 0.25 m² area

Factor	Wheat					Cabbage					Oil pumpkins				
	Epigeic	Endogeic	Anecic	Total number	Total mass	Epigeic	Endogeic	Anecic	Total number	Total mass	Epigeic	Endogeic	Anecic	Total number	Total mass
Production system (PS)															
Control	2.1b	3.3	2.3ab	7.6b	6.1	6.3b	2.5	1.9	10.6b	7.1ab	7.6bc	4.4	3.4	15.4bc	17.4
Conventional	2.8b	2.8	3.9a	9.4ab	12.4	5.1b	2.9	0.1	8.1b	3.1b	4.0c	4.9	3.0	11.9c	17.1
Integrated	2.9b	2.6	1.5b	7.0b	4.8	6.0b	3.5	0.4	9.9b	3.0b	7.0bc	5.4	5.1	17.5abc	28.4
Organic	5.8a	3.4	3.5a	12.6a	11.8	16.0a	6.0	1.0	23.0a	14.8a	11.1ab	5.1	5.9	22.1ab	25.0
Biodynamic	5.5a	4.6	3.4a	13.5a	10.9	11.8a	5.3	1.8	18.8a	7.0ab	13.6a	6.0	6.5	26.1a	29.8
Year (Y)															
2009	3.5	3.7	5.0a	12.1a	14.7a	11.3a	3.4	0.9	15.5	7.2	8.9	6.4a	6.7a	22.0a	28.2
2010	4.2	3.0	0.9b	8.0b	3.7b	6.8b	4.7	1.2	12.7	6.8	8.5	4.0b	2.9b	15.3b	18.9
ANOVA															
Production system (PS)	*	n.s.	*	*	n.s.	***	n.s.	n.s.	**	*	**	n.s.	n.s.	*	n.s.
Year (Y)	n.s.	n.s.	***	**	***	*	n.s.	n.s.	n.s.	n.s.	n.s.	*	*	*	n.s.
PS × Y	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.	**	n.s.	n.s.	n.s.	n.s.

Mean values are presented. Different letters indicate statistically significant differences at 95% probability (Duncan test). Levels of significance: n.s. - non-significant ($p > 0.05$); * ≤ 0.05 ; ** ≤ 0.01 ; *** ≤ 0.001

This is most likely a consequence of FYM and compost applications, as epigeic species live near the surface and feed on coarse particulate organic matter (Bouché 1977), which was added to the plots each year. The epigeic group was also the most abundant group found; thus, this difference between production systems is transferred to the total earthworm count. No differences were observed in the quantity of endogeic species between production systems in any of the crops studied. There was also a trend of more anecic species in ORG and BD systems, with the exception of wheat, where CON plots also contained a relatively large number of vertically burrowing earthworms. CON plots were the only non-harrowed plots in grain production and since anecic species are sensitive to life-space disturbance and their life-cycle expansion occurs in spring time (Edwards and Bohlen 1996), this disturbance on all plots, except CON plots, could be a possible reason for this result. Moreover, small numbers of anecic species on cabbage plots, where harrowing was done two to five times spread over the whole season, seems to confirm this theory. On the contrary, oil pumpkins were harrowed one to two times after crop establishment, then left undisturbed until the end of the growing season (nearly four months), which is reflected in the higher numbers of anecic species, as well as a higher total mass of all earthworms (Table 2.4). Pfiffner and Mäder (1997) attribute the greatest importance regarding differences between production systems found in long-term trials to plant protection management, which seems to be the case in this trial as well.

The difference between years is shown to the greatest extent after wheat and partly after oil pumpkins. The main difference seems to be in the non-presence of anecic species in the year 2010, which is then also transferred to the total earthworm count and biomass. We were unable to pinpoint the exact reason for this, although lack of food (less organic matter remains on the surface) and changed microclimatic conditions in the developmental phase of anecic species could not be excluded.

2.4 Conclusions

Wheat, cabbage and oil pumpkins were produced in three successive years under four different production systems alongside control plots, where yields, the AE of nutrients, and earthworm populations and biomass were measured and evaluated in this trial. The performance of the BD production system in regards to yields was average or above average, as it amounted to 99, 113 and 124 per cent of the average yields for wheat, cabbage and oil pumpkin seeds, respectively. Additionally, the AE of N, N_{min}, P and K of the BD system for the production of all crops studied was in the upper half of all production systems under investigation. Moreover, earthworm populations and biomass were highest and on a similar level in the BD and ORG systems in all three crops investigated. Thus, the BD production system presents a viable alternative to the current predominant CON and INT production systems for the production of wheat, cabbage and oil pumpkins under the Slovene sub-continental temperate climate and would be a step towards ecological intensification in agricultural production systems.

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3 Ecological footprint of wheat and spelt production under industrial and alternative farming systems

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Abstract:

The Industrial Revolution and intensification of agriculture have led to economic activities that profoundly influenced the ecosystem to the point where global environmental stability and geographic political security are jeopardized. Also, uncertainty about oil reserves, rising energy prices and the climate change threat intensified the search for alternative farming systems, where the environmental impact would be lowered. Therefore, the ecological footprint of conventional (CON), integrated (INT), organic (ORG) and biodynamic (BD) farming systems was calculated from data collected in a field trial in Maribor, Slovenia, and interpreted using the SPionExcel tool. Three-year results show a markedly lower ecological footprint of the ORG and BD systems in production of wheat and spelt, mainly due to non-use of external production factors. When yields are added to the equation, the ORG and BD systems also have a lower overall footprint per product unit and higher 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. However, room for improvement exists in the area of machinery use in all systems studied and yield improvement in the ORG farming system.

Keywords:

production systems; organic farming; biodynamic farming; ecological footprint; SPI; ecological efficiency of production

3.1 Introduction

The Industrial Revolution and intensification of agriculture have, for the first time since the emergence of permanent settlements and agriculture more than 12,000 years ago, led to economic activities that profoundly influence the ecosystem to the point where global environmental stability and geographic political security are jeopardized (Rees and Wackernagel 1996; Scialabba and Muller-Lindenlauf 2010). Thus the World Commission on Environment and Development (the Brundtland 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 (WCED 1987). Many interpretations of this definition have emerged over the past years (Bavec et al. 2009); however, the main message it conveys remains the same.

In recent years, numerous tools and methods have emerged that 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). One of these tools is the environmental or ecological footprint (Rees and Wackernagel 1996). It aims to estimate the biologically productive area needed to produce materials and energy used by the population of a certain region (city, state, world). The calculated area is compared to the area available to a certain population or individual, called the biocapacity. In cases where the ecological footprint is greater than the biocapacity, we are in a state where human consumption exceeds the natural carrying capacity (Haberl et al. 2001). Data for the ecological footprint is usually based on statistical data; in the case of agriculture, yearly statistics of individual countries or the FAO (Food and Agriculture Organisation) are used. The drawback of such data lies in its inherent inaccuracy, making the footprint less useful for evaluating smaller units, e.g. single farms.

Other tools based on actual/real data are more appropriate to evaluate individual production processes. A framework for applying such evaluation methods is life cycle assessment (LCA), which assesses the environmental burden caused by a product, a production process, or any activity to provide services (Curran 2008). 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 (van der Werf et al. 2007). 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 to compare the production of field crops in different production systems by the Sustainable Process Index ® (SPI) (Narodoslawsky and Krotscheck 1995, 2000; Krotscheck and Narodoslawsky 1996; Sandholzer and Narodoslawsky 2007), a member of the ecological footprint family. This evaluation method has been customized for agriculture. We used experimental data from a system comparison field trial over three years; therefore results reflect conditions in real-life situations and farming systems. The main question we posed was how sustainable the production systems most commonly used today are and where they can be improved to increase sustainable production of food for future generations. In particular, this will be exemplified in the case of Slovenian wheat and spelt production.

3.2 Materials and methods

3.2.1 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 7m×10m experimental field plots were established on a dystic 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. In one rotation there are typical crops for this region (two years of red-clover grass, wheat, white cabbage, oil pumpkins); in the other one there is an alternative crop rotation (two years of red-clover grass mixture, spelt, red beet, false flax). 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 six years before the trial started in 2007. Four production systems + 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 and are defined by the valid legislation and standards – conventional (CON) (MKGP 2008), integrated (INT) (MKGP 2004, 2008), organic (ORG) (MKGP 2006, 2008; EC 834/2007 2007), biodynamic (BD) (MKGP 2006, 2008; EC 834/2007 2007; Demeter International e.V. 2009) farming system and control (MKGP 2008) 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 3.1). 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.

3.2.2 SPIONExcel tool

The Sustainable Process Index (SPI), developed by Krotscheck and Narodslawsky (1996), 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 resource in a sustainable economy, and anthropogenic as well as natural processes compete for this resource. Therefore area to embed a certain process sustainably into the ecosphere is a convenient measure for ecological sustainability; the more area a process needs to fulfil a service, the more it "costs" from an ecological sustainability point of view.

Table 3.1. Farming systems under investigation in the field trial and differences between them for cereal production

Production system	Soil cultivation and basic operations	Weed management	Pest management	Manure application
Conventional farming according to the Slovene agriculture act and 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 according to Slovene standards for Integrated farming	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 according to the EC regulation on Organic Farming	Ploughing, seedbed preparation, sowing, harvesting	Harrowing 1-2 times/season, cover crops after cereals		1.4 LU of cattle manure /ha
Biodynamic farming according to Demeter International production standards and EC regulation on Organic Farming	Ploughing, seedbed preparation, sowing, harvesting	Harrowing 1-2 times/season, cover crops after cereals	Use of BD preparations	1.4 LU of composted cattle manure /ha with added BD compost preparations
Control plots	Ploughing, seedbed preparation, sowing, harvesting	Harrowing 1-2 times/season	none	none

GAP – good agricultural practice; INT – integrated farming; EC – Council regulation 834/2007; LU – livestock units; BD – biodynamic

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 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” (Sandholzer and Narodoslowsky 2007):

- Principle 1. Anthropogenic mass flows must not alter global material cycles; as in most global cycles (like 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 reader is kindly referred to papers describing this method in depth (e.g. (Narodoslowsky and Krotscheck 2004; Sandholzer and Narodoslowsky 2007)).

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 summarising 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 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:

$$A_{tot} = A_l + A_{fp} + A_m + A_s \quad (m^2) \quad (3.1)$$

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 Eq. (3.2) from the intermediate footprint (up to seed) of a production system:

$$A_s = \frac{A_l + A_{fp} + A_m}{Y_a} \times QS_a \quad (m^2) \quad (3.2)$$

where Y_a stands for quantity (yield) of a crop produced in one year and QS_a for the quantity of seed used in a year.

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

$$a_{tot} = A_{tot} / Y_a \quad (m^2 \text{ kg}^{-1}) \quad (3.3)$$

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 area that is statistically available to a person. 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 (Sandholzer and Narodoslowsky 2007):

$$SPI = \frac{a_{tot}}{a_{inh}} \times 1000 \quad (3.4)$$

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 Eq. (3.5). It provides us with the information on how much of a good or service can be produced on one hectare of surface area in one year with the process or system under study, embedding the provision of this good or service totally and sustainably in the ecosystem.

$$EEP = \frac{Y_a}{A_{tot}} \times 10000 \quad (kg \ ha^{-1}) \quad (3.5)$$

3.2.3 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 one 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 3.2). Because of the nature of the trial, in which not all operations could be done by machine (e.g. spraying), 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.

3.2.4 Statistical analysis

Data for the yield, a_{tot} , SPI and EEP were analysed 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 (Hoshmand 2006). Values given within the paper are means $\pm$ standard error (SE).

Table 3.2. Sample technological chart for wheat (*Triticum aestivum* L. 'Antonius') production in the year 2009

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)
	N-fertilizer (CAN)	666	406	/	/	/	(kg/ha)
	Potassium salt	/	100	/	/	/	(kg/ha)
	Stable manure/compost	/	/	21,450	18,000	/	(kg/ha)
	BD preparations	/	/	/	BD 502-507 each 8-10g	/	
Spraying	50 HP	1.5	1	/	2	/	(h, *)
	Herbicide						
	Boom efekt	5	/	/	/	/	(l/ha)
	Stomp + Axial	5.2	5.2	/	/	/	(l/ha)
	Fungicide						
	Amistar Extra	1	1	/	/	/	(l/ha)
	Insecticide						
	Fastac	0.12	0.12	/	/	/	(l/ha)
	BD preparations	/	/	/	200g BD 500 + 15g 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		5,800	4,920	2,453	3,560	2,678	(kg/ha)
Seed used		200	200	200	200	200	(kg/ha)

Intensity of machinery use: * - light, ** - normal, *** - heavy; HP - horsepower, BD - biodynamic,

3.3 Results and discussion

3.3.1 Yields

Yields of wheat and spelt varied among production systems and years (Table 3.3), whereas there was no significant interaction of both factors. Highest yields of wheat were attained in the CON production system ($4,263 \text{ kg ha}^{-1}$), lowest in the control and ORG production systems ($2,467$ and $2,450 \text{ kg ha}^{-1}$, respectively). Average CON yields are, although lower in comparison with reported yields from other EU countries, in accordance with the average attained yields for wheat in Slovenia in the past years (SURS 2009), whereas ORG wheat yields are relatively low, when we take into account the nutrient input into the farming system each year (Table 3.2). However, the BD and INT systems performed closer to the average of all farming systems (99 and 115 percent of the total average, respectively), and thus point to more balanced yields. Reasons for a relatively high difference between the ORG and BD system could be sought for in use of compost instead of rotted manure in the BD system and/or use of BD preparations, which have been found to improve fertility of soils and nitrate availability in compost in previous studies (Turinek et al. 2009).

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. It is also interesting to notice that highest spelt and lowest wheat yields amount to almost the same value. However, spelt yields were measured on hulled grain and thus additional 20 to 30 percent lower yields have to be taken into account after dehulling (Rozman et al. 2006).

For both wheat and spelt, the influence of the production year on yields is significant, where lowest yields were attained in the year 2008, owing to a long spell of rain at the end of July and thus a late harvest in that year. Yields in 2009 were above average; 2010, however, gave average yields of both grain crops.

Table 3.3. Yields of wheat and spelt depending on production system and year

Factor	Wheat		Spelt	
	Yield (kg ha ⁻¹)	Relative yield ¹ (%)	Yield (kg ha ⁻¹)	Relative yield ¹ (%)
Production system (PS)				
Control	2,467 ± 207c	77	1,807 ± 91b	83
Conventional	4,263 ± 469a	133	2,260 ± 141ab	104
Integrated	3,683 ± 451ab	115	2,369 ± 247a	109
Organic	2,450 ± 263c	76	2,039 ± 125ab	93
Biodynamic	3,136 ± 305bc	99	2,440 ± 180a	112
Year (Y)				
2008	2,530 ± 134b	79	1,851 ± 57b	85
2009	3,882 ± 431a	121	2,550 ± 168a	117
2010	3,186 ± 212ab	100	2,149 ± 108b	98
Average	3,200	100	2,183	100
ANOVA				
PS	***		*	
Y	***		***	
PS × Y	n.s.		n.s.	

¹ average value of each factor=100%

Mean values ± standard errors are presented. Different letters indicate statistically significant differences at 95% probability (Duncan test). Levels of significance: n.s. - non significant (p>0.05); *≤0.05; ***≤0.001

3.3.2 Ecological footprint

When looking at the ecological footprint of production systems for wheat and spelt (Table 3.4 and 3.5), one's attention focuses on the high proportion of the final footprint with CON and INT systems deriving from the use of mineral fertilizers and pesticides. However, ORG and BD systems have relatively high footprints in the field of machinery use impacts, mainly because of spreading organic manure, additional harrowing, and the use of BD preparations in the BD system. The surprising fact is, however, that control plots for wheat and spelt production leave an ecological footprint between 67,216 m² and 74,053 m², respectively. This means that just by using current standard machinery to till the soil and produce crops, we leave a great environmental impact and "consume" seven to eight times more surface area than is needed to plant the crops on. 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, 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 ranges between 758,623 m² to 1,017,110 m², and 521,053 m² to 794,591 m², respectively, is visualized, it takes some effort to perceive and realize the amount of surface area being impacted and/or used by this industrial way of farming. And one can only wonder about the real-life long-term impact it has on the environment and ecosystems. The INT system does not perform any better, although it is publicised and advertised as nature-friendlier and as one of the sustainable agricultural systems (MKGP, 2004). Moreover, footprints differ from year to year, depending on measures needed in a certain year and/or climate conditions. Therefore, average ecological footprints for wheat and spelt for three years of production in this experiment (Figures 3.1 and 3.2) even out the extremes and offer a good average picture.

Table 3.4. Partial and total footprints of wheat production for the years 2008, 2009 and 2010 (m² ha⁻¹)

Year	Production system	Footprint category								Total footprint
		Production area	% of total footprint	Seeds	% of total footprint	Machinery use	% of total footprint	Fertilization and plant protection	% of total footprint	
2008	Conventional	10,000	1	51,675	7	67,357	9	651,669	83	780,701
	Integrated	10,000	1	43,767	7	68,391	10	544,523	82	666,681
	Organic	10,000	10	7,507	7	86,063	83	0	0	103,570
	Biodynamic	10,000	9	6,845	6	92,339	85	0	0	109,184
	Control	10,000	14	5,611	8	57,788	79	0	0	73,399
2009	Conventional	10,000	1	33,570	3	72,064	7	901,476	89	1,017,110
	Integrated	10,000	2	24,492	4	71,529	11	530,977	83	636,998
	Organic	10,000	10	7,017	7	86,063	83	0	0	103,080
	Biodynamic	10,000	9	5,188	5	92,339	86	0	0	107,526
	Control	10,000	14	4,316	6	57,788	80	0	0	72,104
2010	Conventional	10,000	1	34,083	4	66,960	9	647,580	85	758,623
	Integrated	10,000	2	33,633	6	66,960	11	491,845	82	602,438
	Organic	10,000	10	6,257	6	81,494	83	0	0	97,751
	Biodynamic	10,000	10	5,473	5	86,201	85	0	0	101,674
	Control	10,000	15	3,997	6	53,219	79	0	0	67,216

Table 3.5. Partial and total footprints of spelt production for the years 2008, 2009 and 2010 (m² ha⁻¹)

Year	Production system	Footprint category								Total footprint
		Production area	% of total footprint	Seeds	% of total footprint	Machinery use	% of total footprint	Fertilization and plant protection	% of total footprint	
2008	Conventional	10,000	2	48,587	9	67,357	13	406,390	76	532,334
	Integrated	10,000	2	46,973	10	68,391	15	326,492	72	451,856
	Organic	10,000	9	10,167	10	86,063	81	0	0	106,230
	Biodynamic	10,000	9	8,943	8	92,339	83	0	0	111,282
	Control	10,000	14	6,264	8	57,788	78	0	0	74,053
2009	Conventional	10,000	1	56,896	7	77,077	10	650,619	82	794,591
	Integrated	10,000	2	30,760	6	74,871	15	381,600	77	497,231
	Organic	10,000	10	7,098	7	86,063	83	0	0	103,161
	Biodynamic	10,000	9	6,937	6	99,023	85	0	0	115,959
	Control	10,000	14	5,942	8	57,788	78	0	0	73,731
2010	Conventional	10,000	2	41,549	8	66,960	13	402,543	77	521,053
	Integrated	10,000	2	30,022	7	66,960	16	301,261	74	408,244
	Organic	10,000	10	8,149	8	81,494	82	0	0	99,644
	Biodynamic	10,000	10	7,183	7	86,201	83	0	0	103,384
	Control	10,000	14	6,530	9	53,219	76	0	0	69,749

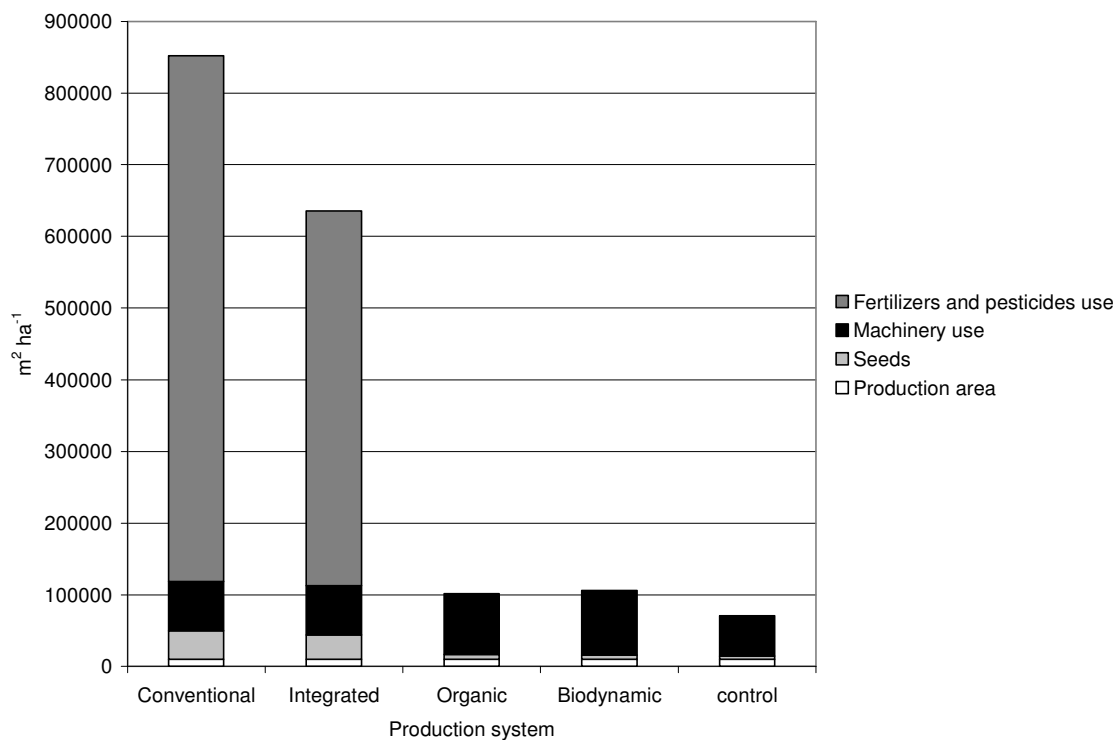


Figure 3.1. Average Yearly Ecological Footprint of Wheat Production for years 2008-2010

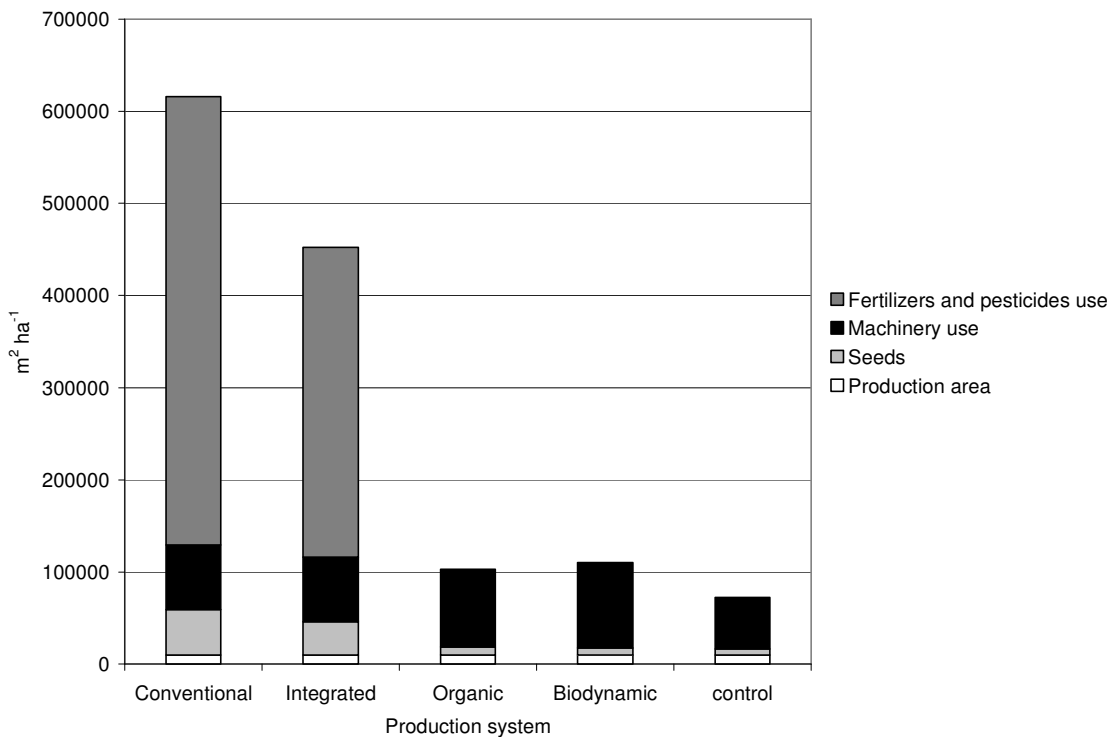


Figure 3.2. Average Yearly Ecological Footprint of Spelt Production for years 2008-2010

3.3.3 Overall footprint of a product, SPI and Ecological Efficiency of Production

Results for the a_{tot} , SPI and EEP give an even more insightful picture, as yields are taken into the equation (Table 3.6). 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 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 two years.

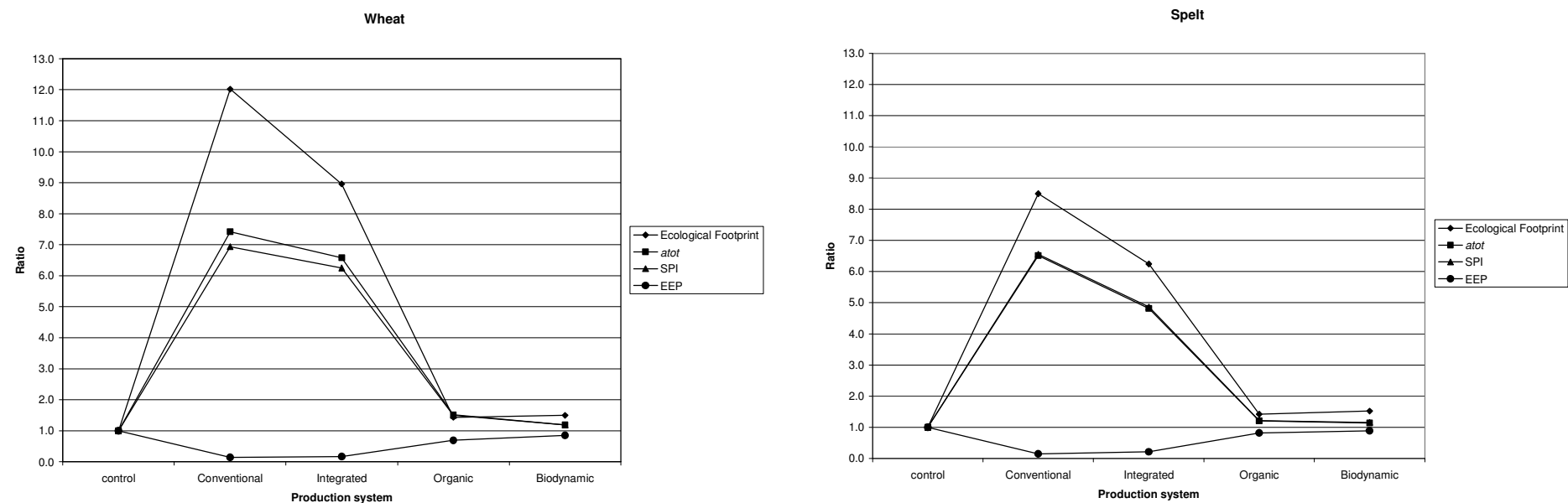
Ratios between farming systems, where control=1, provide us with a visual overview as to what influence production systems as such and yields have on the performance of farming systems under study (Figures 3.3 and 3.4). It turns out that higher yields in CON and INT systems can partly compensate for 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.

It has to be added that nowadays 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 percent of the total agricultural area being managed organically (Willer and Kilcher 2010). Where does that leave us in the future, when we take into account the results from this trial? One of the main objectives against organic farming is that it does not produce enough food to feed the whole population – now and in the future (Avery 2007). However, several research projects and reports have demonstrated otherwise (Pretty et al. 2006; Badgley et al. 2007). Even if yields in developed European countries, where CON industrial agriculture is now predominant, would be 5 to 20 percent lower with ORG and BD agriculture, population projections for developed countries in the next 50 years partly coincide with these lower yields (UNPP 2008). 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 (SURS 2009).

Table 3.6. Overall footprint per unit (a_{tot}), Sustainable Process Index (SPI) and Ecological Efficiency of Production (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
Conventional	230 ± 22a	3.33 ± 0.28a	49 ± 4c	280 ± 19a	4.26 ± 0.29a	37 ± 2c
Integrated	204 ± 19a	3.00 ± 0.30a	58 ± 7c	207 ± 21b	3.16 ± 0.32b	53 ± 5c
Organic	47 ± 5b	0.72 ± 0.08b	242 ± 26b	52 ± 4c	0.79 ± 0.06c	202 ± 12b
Biodynamic	37 ± 3b	0.57 ± 0.05b	296 ± 29ab	49 ± 4c	0.75 ± 0.06c	219 ± 21ab
Year (Y)						
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.

Mean values ± standard errors 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 ($p > 0.05$); * ≤ 0.05 ; ** ≤ 0.01 ; *** ≤ 0.001



Figures 3.3 and 3.4. Ecological Footprint, Overall Footprint per unit (a_{tot}), Sustainable Process Index (SPI) and Ecological Efficiency of Production (EEP) ratios between production systems for three years of wheat and spelt production

A large competition for grain and animal manures is also present in the developing “bio-gas” sector (Ošljaj et al. 2010). In this sense there is a relatively great reserve in arable land, which could be used for food, instead of feed or energy production. And 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 backside 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 eventually wipe out those human numbers anyway. Without abundant oil, on the other hand, a large population will not be possible (Hanlon and McCartney 2008). It has to be noted that there are as many proponents as there are opponents toward the “peak-oil” theory (Hanlon and McCartney 2008; Wilkinson 2008; Leder and Shapiro 2008; Verbruggen and Al Marchohi 2010), yet one thing remains sure. Fossil oil renewal rates and quantities are much slower than the current usage rates and quantities, 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 3.7). Production levels would be lower by almost a third, the ecological footprint and a_{tot} , however, would be lower by almost two-thirds (Figure 3.5). 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 percent of that wheat had to be imported (SURs 2009). 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?

Table 3.7. Land use for wheat and spelt production in Slovenia in 2010 with the corresponding ecological footprint and simulated change with the eventual change of farming practice in 2015 and 2050

Production system (PS)	Wheat				Spelt			
	Area (ha)	% of total wheat area	Resulting footprint (m ²)	Total yield (kg)	Area (ha)	% of total spelt area	Resulting footprint (m ²)	Total yield (kg)
Situation in 2010^a								
Conventional	18,599	59	15,849,136,046	79,288,006	50	23	30,818,106	113,068
Integrated	12,885	41	8,186,881,569	47,456,081	24	11	10,908,411	57,117
Organic	206	1	20,812,870	502,544	143	66	14,728,581	291,536
Biodynamic	0	0	0	0	0	0	0	0
Total	31,690	100	24,056,830,485	127,246,631	217	100	56,455,098	461,721
Projection 2015^b								
Conventional	0	0	0	0	0	0	0	0
Integrated	25,352	80	16,107,961,443	93,371,416	282	10	127,381,377	666,971
Organic	3,552	19	360,410,071	8,702,400	2,252	80	232,015,627	4,592,497
Biodynamic	187	1	19,845,970	595,782	282	10	31,028,269	686,960
Total	29,091	100	16,488,217,484	102,669,598	2,815	100	390,425,273	5,946,427
Simulation 2050^c								
Conventional	0	0	0	0	0	0	0	0
Integrated	3,169	10	2,013,495,180	11,671,427	0	0	0	0
Organic	14,625	70	1,483,951,940	35,831,250	7,948	80	818,686,573	16,205,010
Biodynamic	4,178	20	443,403,538	13,311,108	1,987	20	218,971,694	4,847,992
Total	21,972	100	3,940,850,658	60,813,785	9,934	100	1,037,658,267	21,053,002

^a 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.

Yields per hectare are taken from this trial. ^b according to the Slovene Action Plan for Organic Farming (Hrustel-Majcen et al. 2006), 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. ^c simulation is based on the assumption that by 2050, conventional energy sources (oil, gas, coal, 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.

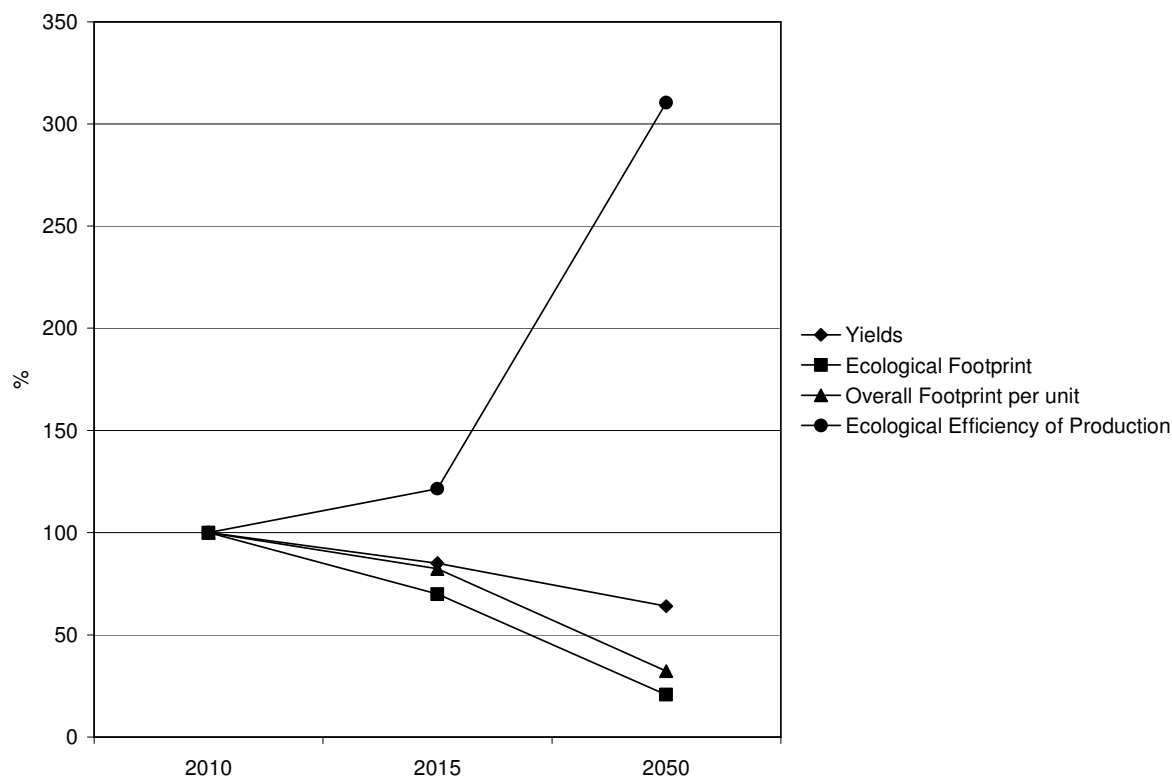


Figure 3.5. Projected change of total yields, Ecological Footprint, Overall Footprint per unit, and Ecological Efficiency of Production from 2010 to 2050 for wheat and spelt production in Slovenia

Possible solutions can be sought in changing crop rotations (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. (2005) 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 (Wenz 2010), where fuel use per hectare has been lowered to 20 to 30 l ha⁻¹ (it amounted to more than 90 l ha⁻¹ in our study); yields,

however, remained stable around the average yields of Germany. Another example is the reinvention and improvement of the ridge-till system (Turiel 2009) in order to lower machinery use and improve the quality of soils and consequently the health of plants and quantity of produce. Converting diesel engines to drive only on plant oil (Elsbett 2010) combined with lowered fuel use is a prominent and urgent short-term future perspective in order to produce food in a mechanised way in the near and distant future. However, all these improvements and approaches need further research and development in order to adapt them to different microclimatic, pedologic and cultural conditions.

3.4 Conclusions

We recorded the parameters of production for wheat and spelt in a field system comparison trial and calculated the partial, overall and total footprints each production system has on the environment. Furthermore, the SPI and EEP of production were determined. All parameters were applied in a simple future projection model in the case of Slovenian wheat and spelt production.

Our results indicate critical points in production of these two grain crops in each production system, where greatest improvement 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 of the recorded parameters and to get closer to sustainable farming systems from a productive and environmental point of view.

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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4 Sensory quality of white cabbage and red beet from industrial and alternative farming systems

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Abstract

In recent years, the importance of food quality has increased, but there remains a lack of research in this field. Sensory properties are also one of the characteristics that determine the quality of food. Organic food is considered tastier, but results of surveys are sometimes contradictory. We examined yields and sensory properties of white cabbage and red beet, which were, in addition to the control sample, produced in conventional (CON), integrated (INT), organic (ORG), and biodynamic (BD) production systems (PS) in two successive years. Yields did not differ significantly among the production systems. A total of 167 consumers scored four attributes (color, odor, taste, and willingness to buy) using a nine-point hedonic scale. Results show significant differences between PS for both crops, whereas there was a significant interaction of PS and year of production only for cabbage. The importance of seasonal variability is put into perspective, and a need for detailed PS comparisons for other crops in successive years under controlled conditions is discussed.

Practical Applications

Organic farming is growing in production area and consumption all over the world, especially Europe and Northern America. Understanding the effects of alternative production systems on properties of vegetables, in this case white cabbage and red beet, presents important information for stakeholders involved in the production of food (e.g. In designing further research, advertising, consumer education). Also the willingness to buy vegetables, depending on production system, can serve as an orientation for producers as to which production system to choose for better economic performance of their farms/enterprises.

Key words:

organic agriculture; biodynamic agriculture; sensory evaluation; farming system comparison

4.1 Introduction

Consumers are becoming increasingly concerned about food quality, especially regarding how, when, and where food is produced and what impact it has on the environment (Reganold et al. 2010; Bavec et al. 2010). This is reflected in the demand for organic certified products as well (De Souza et al. 2007). In addition, consumer and research interest in the biodynamic farming system is posing questions regarding food quality (Turinek et al. 2009), which have yet to be answered.

Moreover, amongst consumers, sensory quality is one of the more important parameters used to determine the quality of food (Yiridoe et al. 2005). The importance of research on the taste of fruits and vegetables has increased with organic farming, as people want to know if they are provided with a product that has different taste characteristics in comparison to conventional farming (Talavera-Bianchi et al. 2010). In general, organic food is considered tastier, but results of surveys are sometimes contradictory (Bourn and Prescott 2002). Often, contradictions appear because of discrepancies in the evaluation design and process (unevenly ripe vegetables, different varieties, different origin, inappropriate storage of vegetables, different distribution channel, etc.). Sometimes, there are just no differences present and/or detectable to the human sense (Benbrook et al. 2008). Even though some authors advocate the use of trained panelists in order to attain more consistent results (Theurer 2006), hedonic sensory evaluation aims at determining the acceptability of a product and/or preference of a given product compared to another one from the point of view of the consumer (Lawless and Heymann 1998; Meilgaard et al. 2007).

Food quality comparisons of white head cabbage (*Brassica oleracea* L. var. *capitata* L. f. *alba*) and (even more so) of red beet (*Beta vulgaris* L. ssp. *vulgaris*) originating from industrial and alternative farming systems have so far mainly been made on the basis of chemical and biochemical properties (Warman and Havard 1997; Citak and Sonmez 2010; Bavec et al. 2010). Differences in the sensory properties of these two vegetables have rarely been evaluated or determined. In the few cases of cabbage comparisons (Hansen 1980; Fjellkner-Modig et al. 2001), sensory evaluation has been a side focus of a broader study with few evaluators and non-detailed descriptions of evaluating procedures/results.

In both cases, no differences were detected between conventional and organic production. Only one study comparing red beet from industrial and alternative farming systems regarding its sensory properties was found (Hansen 1980), where no differences between farming systems were detected.

Thus, the main question we asked ourselves was whether there are any differences between industrial and alternative farming systems detectable to a large consumer group. Therefore, the sensory properties of white cabbage and red beet samples were examined, which were, in addition to the control plots, produced in conventional (CON), integrated (INT), organic (ORG), and biodynamic (BD) farming systems in a long-term controlled field trial in two successive years and afterwards evaluated by two groups of consumers. As mentioned previously, to our knowledge, as of yet, no similar studies have been done comparing hedonic sensory quality of white cabbage and red beet in all of these various production systems. Therefore, the production systems and sensory evaluation methods are explored in the first part of the paper, followed by an examination of the production and evaluation results with a focus on production system, year of production (evaluator group), and sex of evaluators as factors. We conclude the paper with an affirmation that production systems do have a significant influence on the hedonic sensory profile and acceptance of both white cabbage and red beet.

4.2 Materials and methods

4.2.1 Long-term field trial

The experimental site for the production of the experimental material was 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 yearly mean air temperature of the area is 10.7 °C, where the mean monthly minimum is in January with 0.4 °C, and the average monthly maximum is in July with 20.8 °C. The average annual rainfall in the area is around 1000 mm. Twenty 7m×10m experimental field plots were established in 2007 on a dystric cambisol (deep) and were maintained within two different five-course crop rotation designs, where various

sequences of crops in the crop rotations were used. In one rotation, there were typical crops for this region (two years of red-clover grass, wheat, white cabbage, and oil pumpkins); the other one was an alternative crop rotation (two years of red-clover grass mixture, spelt, red beet, and false flax). Four production systems and control plots (no fertilization or plant protection) were arranged in a randomized complete block split-plot design with four replicates. 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. Soil cultivation, sowing, and harvesting were identical among experimental plots and were performed on similar dates and in a similar manner to adjacent fields. The farming systems differed mostly in plant protection and fertilization strategies, and they were managed in accordance with the laws and rules defining each farming system (MKGP 2002, 2006, 2008; EC 834/2007 2007; Demeter International e.V. 2009). Amounts of NPK nutrients applied in each year are presented in Table 4.1. The reader is kindly referred to previously published publications (Bavec et al. 2010) for a detailed description of differences between farming systems.

The same varieties of crops were used in all farming systems, where the origin of the seed differed – organically grown for the ORG, BD, and control plots vs. conventionally grown for CON and INT plots. The white cabbage variety ‘Kranjsko okroglo’ was chosen, as it is a traditional local variety for fresh and sauerkraut consumption and its seed was available in CON and ORG origin. As for red beet, the variety ‘Rote Kugel’ was chosen, as it was the only one available in both CON and ORG origin.

Samples of cabbage were harvested on September 29 and 30, 2008 and September 30, 2009. Red beet samples were picked on August 19, 2008 and September 9 and 10, 2009 from the center (10 m²) of the experimental plots. Afterwards, they were cleaned and stored at optimal conditions (Henze and Baumann 1979) in a cooling room at 6 °C and 90% relative humidity until the sensory evaluation took place.

In order to determine the dry matter (DM) content, ten freshly picked roots/heads per plot were weighed, then oven dried at 70 °C for 72 h, and then weighed again. The DM content is expressed as percent of total fresh weight.

Table 4.1. Amount of nutrients (NPK) applied in white cabbage (*Brassica oleracea* L. var. *capitata* L. f. *alba* 'Kranjsko okroglo') and red beet (*Beta vulgaris* L. ssp. *vulgaris* 'Rote Kugel') production in the years 2008 and 2009

Production system	2008			2009		
	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)	N (kg ha ⁻¹)	P (kg ha ⁻¹)	K (kg ha ⁻¹)
<u>White cabbage</u>						
Conventional farming	143	70	300	155	70	300
Integrated farming	153	30	300	165	30	300
Organic farming ¹	107	27	55	106	36	162
Biodynamic farming ¹	107	27	55	112	57	45
Control plots	0	0	0	0	0	0
<u>Red beet</u>						
Conventional farming	89	70	300	125	70	300
Integrated farming	94	30	300	130	30	300
Organic farming ¹	107	27	55	106	36	162
Biodynamic farming ¹	107	27	55	112	57	45
Control plots	0	0	0	0	0	0

N – nitrogen; P – phosphorus; K – potassium; ¹ – cattle manure and composted cattle manure added in organic and biodynamic farming, respectively, were analyzed for their contents of NPK before application each year

4.2.2 Sample preparation

Each year, on the day of the sensory evaluation, the stored samples of cabbage heads were washed, cut into 5 mm stripes, mixed to achieve homogeneous samples, and stored in coded closed plastic containers in a standard freezer (≈5 °C) until needed in the sensory evaluation. A similar procedure was used for red beet, where roots were washed, peeled, grated, homogeneously mixed, and afterwards stored in the same freezer. Five pooled

samples of each vegetable crop were freshly served monadically on open white plastic trays marked with three-digit random numbers. Additionally, a plastic fork was offered. Each serving weighed around 17 g. Serving orders were randomized.

4.2.3 Sensory evaluation

The first year's evaluation took place during the 12th Alpe Adria Biosymposium, which was held on November 20, 2008 at the Faculty of Agriculture and Life Sciences in Hoče, Slovenia where consumers, farmers, advisers, policy makers, and students interested in organic farming met. The next year's evaluation took place on the first day of the final conference of the EuroMARC project entitled "The Development of Mountain Quality Food Products - Production, Distribution, Consumption." This was held on December 3, 2009 at the same locality, where stakeholders from a broad field of knowledge, expertise, and experiences convened (food scientists, sociologists, producers, consumers, policy makers, students, etc. engaged in production, distribution, or research on food). The hedonic sensory evaluation was offered each year as an accompanying event, and it took place in a room where 20 separate white tables (0.80 × 1.8 m) with ample room between them were provided for the volunteers who were willing to take part in the evaluation. Each evaluator was accompanied to the table, was handed the evaluation sheet, and was shortly explained the purpose and procedure of the hedonic evaluation. A 9-point hedonic scale was chosen, as it was found to be as effective as the labeled affective magnitude scale (Lawless et al. 2010) and suited the needs of this research well. On the scale, 1 was marked as "extremely dislike," 9 as "extremely like," and 5 as "neither like nor dislike" for color, odor, and taste. Willingness to buy was evaluated on a 9-point scale as well, where 1 was marked as "extremely unwilling," 5 as "neither unwilling nor willing," and 9 as "extremely willing." White plain bread and tap water were at disposal to neutralize taste. The evaluation took place at 20 °C, and the lecture room was lit by a combination of standard fluorescent fixtures and sunlight provided by large, unshaded windows.

4.2.4 Statistical analysis

Data for the yields were analyzed by a multifactor ANOVA with production system and

year as factors using Statgraphics Centurion (Version XV, StatPoint Technologies, Inc., Warrenton, VA). This was followed by least squares means comparisons after Duncan (Hoshmand 2006). Attained data for the sensory evaluation were treated and analyzed as a split-plot one-within and two-between design (Lawless and Heymann 1998; Stone and Sidel 2004) in order to determine and separate the influence of the panels (years), sex of evaluators, and production systems on the final scores. This was done using the GLM repeated measures procedure (SPSS 16, SPSS Inc., Chicago, IL) for each crop and attribute separately. Production system was the within factor in the model, and year of production (panels) and sex of evaluators were the between factors in the model. To examine correlations between the sensory attributes, a correlation analysis was performed.

4.3 Results and discussion

4.3.1 Yields

White cabbage and red beet were produced and harvested in two-successive seasons in four different production systems and a control treatment. Yields varied significantly amongst the years but not amongst the production systems (Table 4.2). Despite this, notable differences between the average marketable yields of the various production systems existed, where highest yields for cabbage were attained in the alternative, ORG, and BD production systems, followed by INT, CON, and control plots. This order was slightly different for red beet, where highest relative yields were measured in the BD plots, followed by INT, ORG, CON, and control plots.

The influence of years shows itself in an inverse picture, as in 2008, higher yields were attained for white cabbage, and in 2009, higher yields were attained for red beet, as compared to 2009 and 2008, respectively. There was no significant interaction between production systems and years.

DM yields did not significantly differ between production systems either (Table 4.2); however, a trend towards higher DM contents in red beet under alternative production systems was observable (Figure 4.1).

Table 4.2. Yields of white cabbage and red beet depending on production system and year

Factor	White cabbage				Red beet			
	Marketable yield (kg ha ⁻¹)	Relative yield ¹ (%)	DM yield (kg ha ⁻¹)	Relative DM yield ¹ (%)	Marketable yield (kg ha ⁻¹)	Relative yield ¹ (%)	DM yield (kg ha ⁻¹)	Relative DM yield ¹ (%)
Production system (PS)								
Control	21,477 ± 5,828	77	1,871 ± 482	83	16,880 ± 2,933	75	1,719 ± 433	71
Conventional	25,836 ± 2,959	93	1,938 ± 219	86	17,930 ± 7,651	79	1,856 ± 925	77
Integrated	28,440 ± 5,253	102	2,124 ± 289	94	24,628 ± 8,585	109	2,451 ± 1,093	101
Organic	31,645 ± 6,074	114	2,777 ± 436	123	24,246 ± 6,468	107	2,758 ± 1,018	114
Biodynamic	31,776 ± 5,433	114	2,586 ± 362	114	29,193 ± 4,927	129	3,324 ± 938	137
Year (Y)								
2008	33,254 ± 3330a	119	2,519 ± 269	112	15,927 ± 1,555b	71	1,082 ± 119b	45
2009	22,416 ± 2527b	81	1,999 ± 185	88	29,225 ± 4,881a	129	3,761 ± 610a	155
Average	27,836	100	2,259	100	22,576	100	2,422	100
ANOVA								
PS	n.s.		n.s.		n.s.		n.s.	
Y	**		n.s.		**		***	
PS × Y	n.s.		n.s.		n.s.		n.s.	

¹ average value of each factor=100%; DM – dry matter

Mean values ± standard errors are presented. Different letters indicate statistically significant differences at 95% probability (Duncan test). Levels of significance: n.s. - non significant (p>0.05); **≤0.01; ***≤0.001

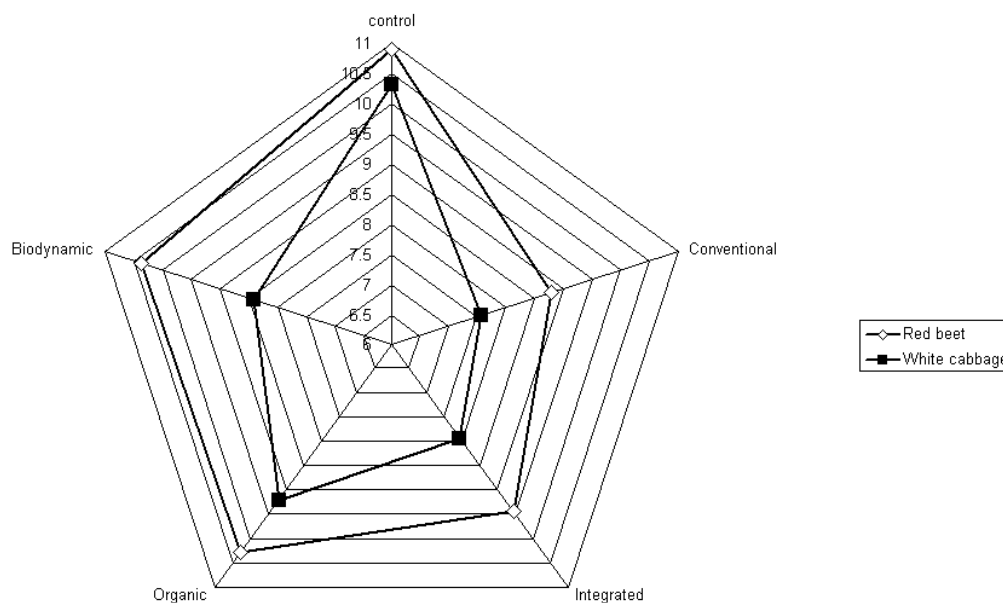


Figure 4.1. Dry matter contents of white cabbage and red beet in two successive seasons (in percent)

4.3.2 Sensory evaluation scores

A total of 167 evaluators took part in the sensory evaluation. The detailed demographic data for each year is presented in Table 4.3. The group of evaluators in 2008 was more balanced across age and education levels as compared to the group in 2009, where there was a higher percentage of the age-class between 20 and 29 years. This difference was not reflected, however, in the evaluation scores, as the only attribute differently evaluated leading back to the two different groups and sexes was the color of white cabbage (Figure 4.2).

Table 4.3. Demographic data of sensory evaluation participants in years 2008 (N=91) and 2009 (N=76) (in percent)

Variable	Classes	Year	
		2008	2009
Sex	Female	59	51
	Male	41	49
Age (in years)	20-29	34	70
	30-39	22	12
	40-49	22	10
	50-59	15	7
	60-69	7	1
	70-79	0	0
Level of education	High school	30	61
	Professional college ¹	13	9
	Undergraduate	47	17
	Post-graduate	10	13

¹ – 2-3-year non-university degree common in central European countries

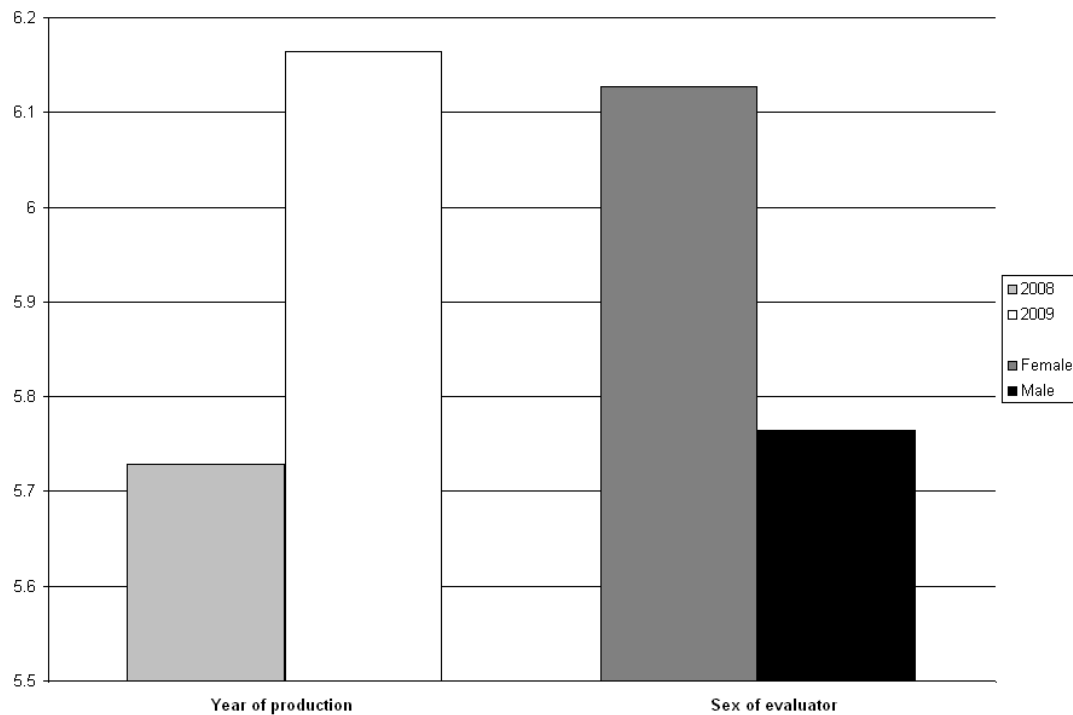


Figure 4.2. Color scores of white cabbage dependent on production year (group of evaluators) and sex of evaluators

4.3.2.1 White cabbage

White cabbage differed significantly between the production systems regarding odor and willingness to buy (Table 4.4). Consumers preferred the odor of control cabbage to CON cabbage, with INT, BD, and ORG in-between (Figure 4.3). They were most willing to buy INT cabbage, followed by control, ORG, BD, and CON samples. However, significant differences were also observed in the interaction of production system and year of production (Figure 4.4), where contrasting results were obtained for cabbage from control (color) and BD plots (all parameters assessed), whereas other systems were evaluated more consistently. These discrepancies could be explained by yield quantity and plant protection/fertilization strategies (more remains of clover-grass residues in 2008 compared to 2009 on control plots, 2nd year use of BD preparations in 2009) with a resulting changed chemical composition. This was shown to be the case with some other crops (Warman and Havard 1997; Mikulic Petkovsek et al. 2009; Bavec et al. 2010) as a response of plant resilience towards changed growing conditions. However, yields remained stable in BD plots in both years (data not shown). Not only could the amount of nutrients applied have been a factor in the taste differences (Table 4.1), but also the form of the nutrients applied could have affected taste and yield, which was shown to be the case in tomatoes (Heeb et al. 2005). Different consumer preferences could also have affected evaluation scores. However, as mentioned previously, a significant influence of year of production (and thus consumer panel) was found only for the color scores and not for other attributes. The evaluation scores also differed significantly between sexes and production systems when it came to the question of how willing they were to buy the evaluated sample. Females were more inclined to buy cabbage in general, being most willing to buy INT cabbage, followed by control, CON, BD, and ORG cabbage, whereas men expressed a similar preference for ORG, INT, and control samples, followed by BD and CON samples (Figure 4.5).

Table 4.4. Influence of production system, year, and sex of evaluators in a split-plot one-within and two-between design for white cabbage and red beet (F-values followed by significance level)

Factor	White cabbage				Red beet			
	Color	Odor	Taste	Willingness to buy	Color	Odor	Taste	Willingness to buy
Production system (PS)	1.299 n.s.	3.874 **	1.496 n.s.	3.770 **	5.070 ***	1.389 n.s.	2.488 *	2.510 *
Year (Y)	6.798 **	2.271 n.s.	0.239 n.s.	0.05 n.s.	1.129 n.s.	0.103 n.s.	0.155 n.s.	0.218 n.s.
Sex of evaluator (S)	4.717 *	0.631 n.s.	1.928 n.s.	3.646 n.s.	0.233 n.s.	0.078 n.s.	0.397 n.s.	0.561 n.s.
PS × Y	10.355 ***	3.576 **	6.511 ***	7.020 ***	1.211 n.s.	1.756 n.s.	2.261 *	1.461 n.s.
PS × S	0.921 n.s.	2.244 n.s.	1.472 n.s.	2.379 *	2.820 *	0.967 n.s.	1.615 n.s.	1.796 n.s.
Y × S	5.667 *	1.929 n.s.	0.705 n.s.	1.075 n.s.	0.735 n.s.	2.086 n.s.	1.256 n.s.	0.804 n.s.
PS × Y × S	0.583 n.s.	1.614 n.s.	0.302 n.s.	0.596 n.s.	1.569 n.s.	1.821 n.s.	0.710 n.s.	0.834 n.s.

Levels of significance: n.s. - non-significant ($p > 0.05$); * ≤ 0.05 ; ** ≤ 0.01 ; *** ≤ 0.001 .

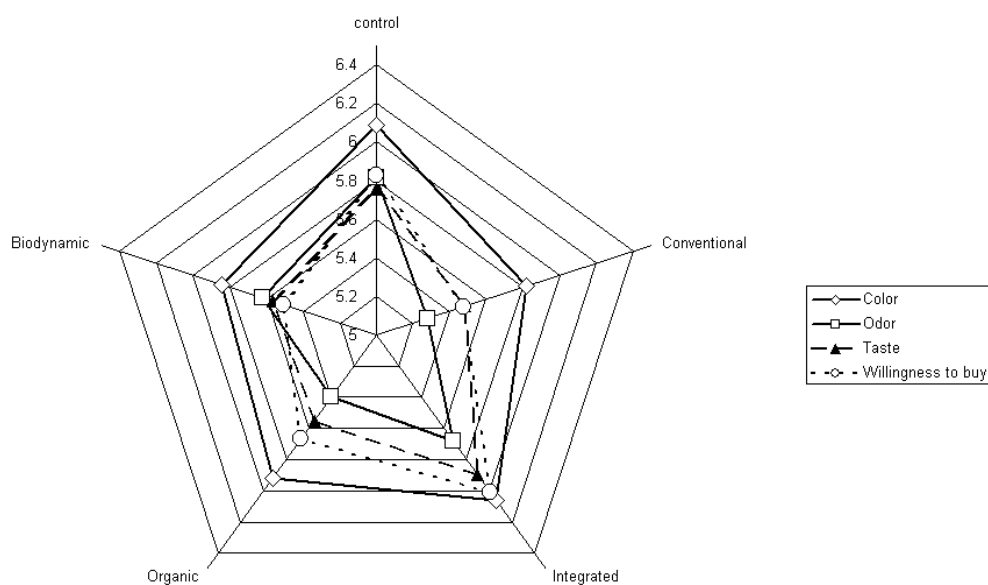


Figure 4.3. Sensory evaluation profiles of white cabbage depending on production system

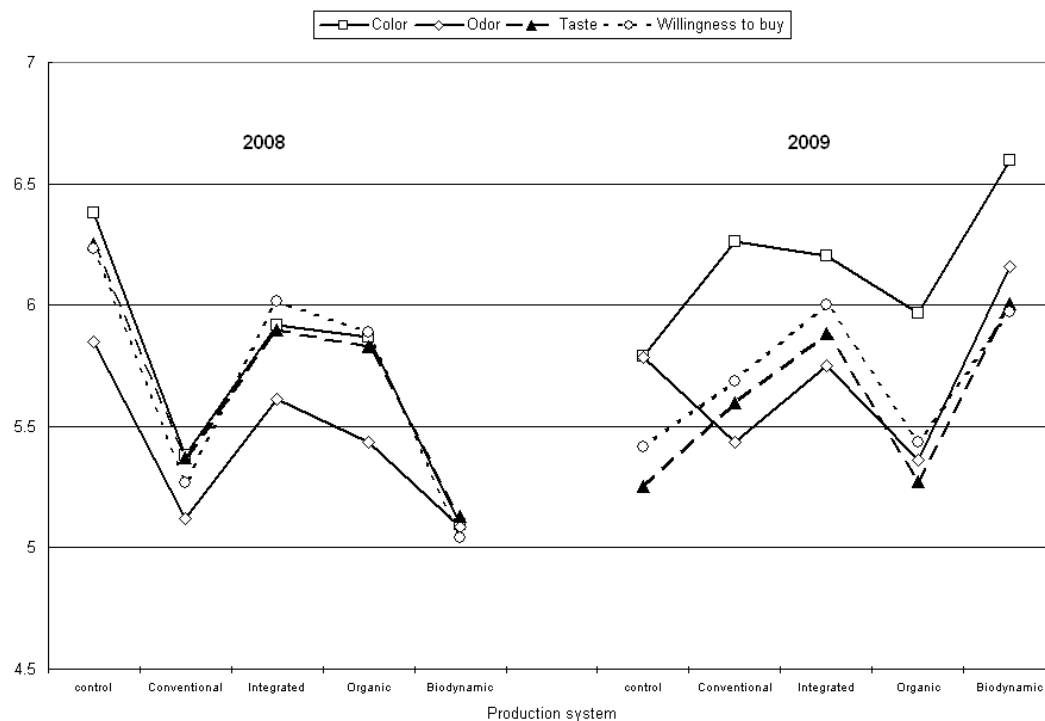


Figure 4.4. Sensory evaluation profiles of white cabbage depending on the production system and year of production

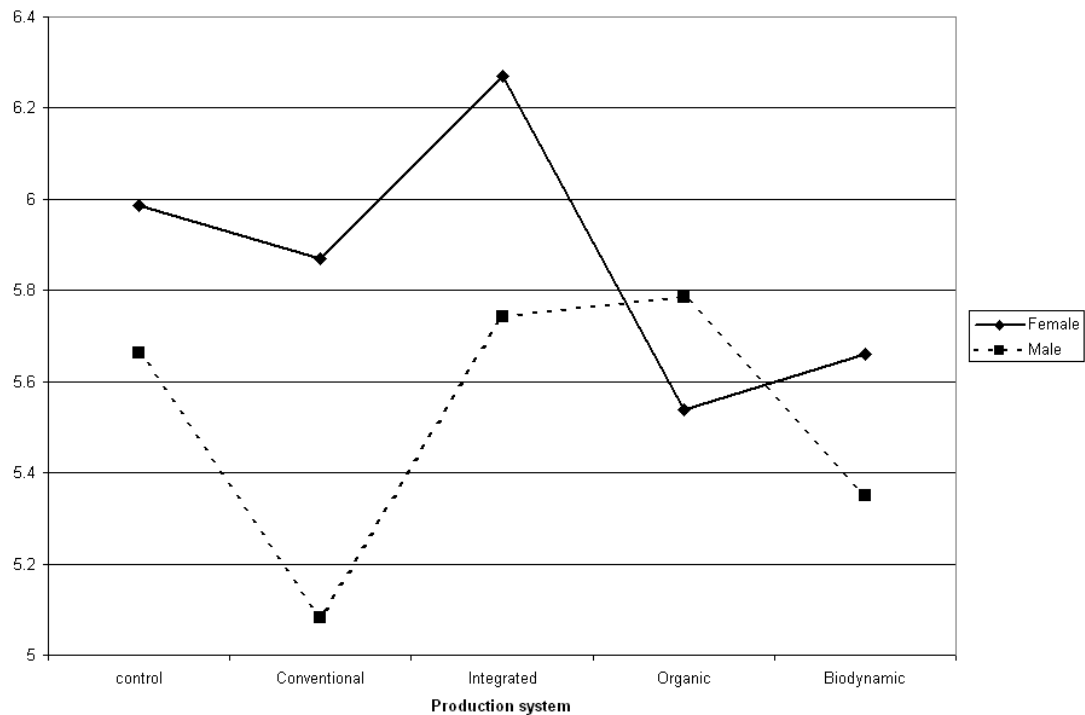


Figure 4.5. Willingness to buy white cabbage depending on sex of evaluator

4.3.2.2 Red beet

Control and BD samples of red beet attained the highest scores for color, taste, and willingness to buy, followed by ORG, INT, and CON samples (Figure 4.6). A reason for the significant differences in taste and willingness to buy between BD and ORG red beet may lie in sugar contents or phenolic compounds, which were shown to be higher in BD-produced beet (Bavec et al. 2010). Odor scores did not differ significantly between production systems. Only taste was evaluated differently between the two years and production systems (Figure 4.7). That is, in 2008, differences between control and CON samples were more pronounced, whereas they were scored more uniformly in 2009.

Again, differences between sexes became visible in the evaluation of the color of red beet samples, where males scored more uniformly than females (Figure 4.8). However, the trend of giving higher scores to alternative farming systems was visible for both sexes.

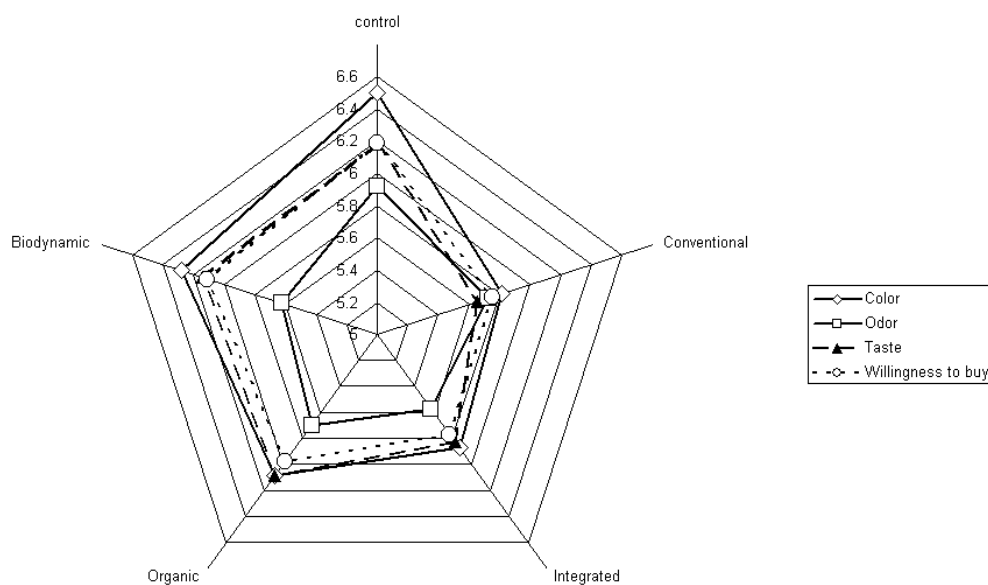


Figure 4.6. Sensory evaluation profiles of red beet depending on production system

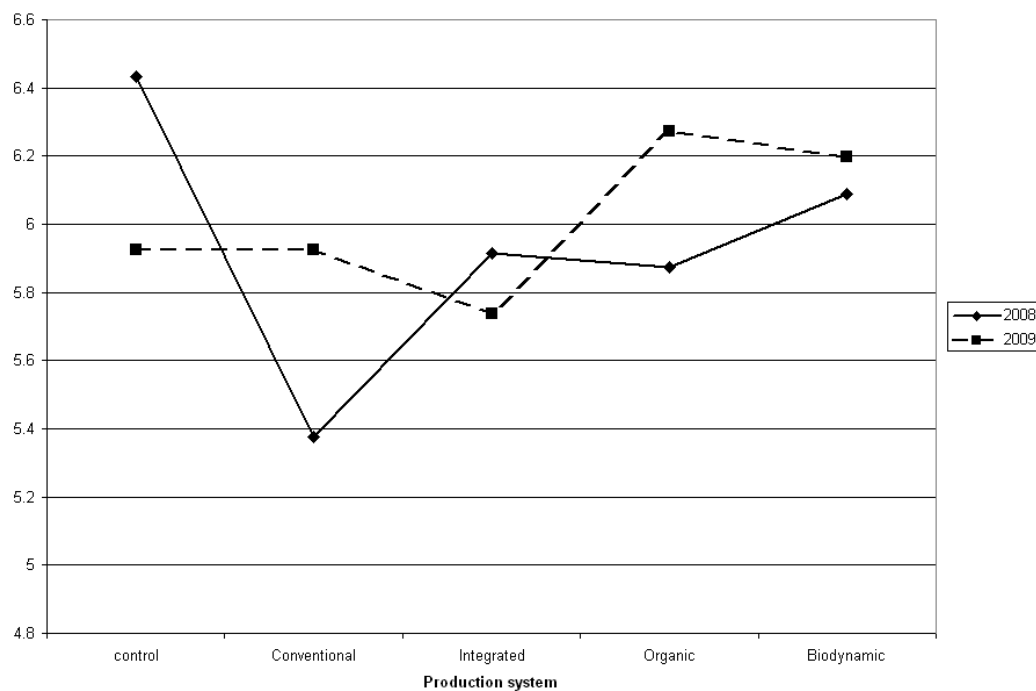


Figure 4.7. Taste of red beet depending on production system and year of production

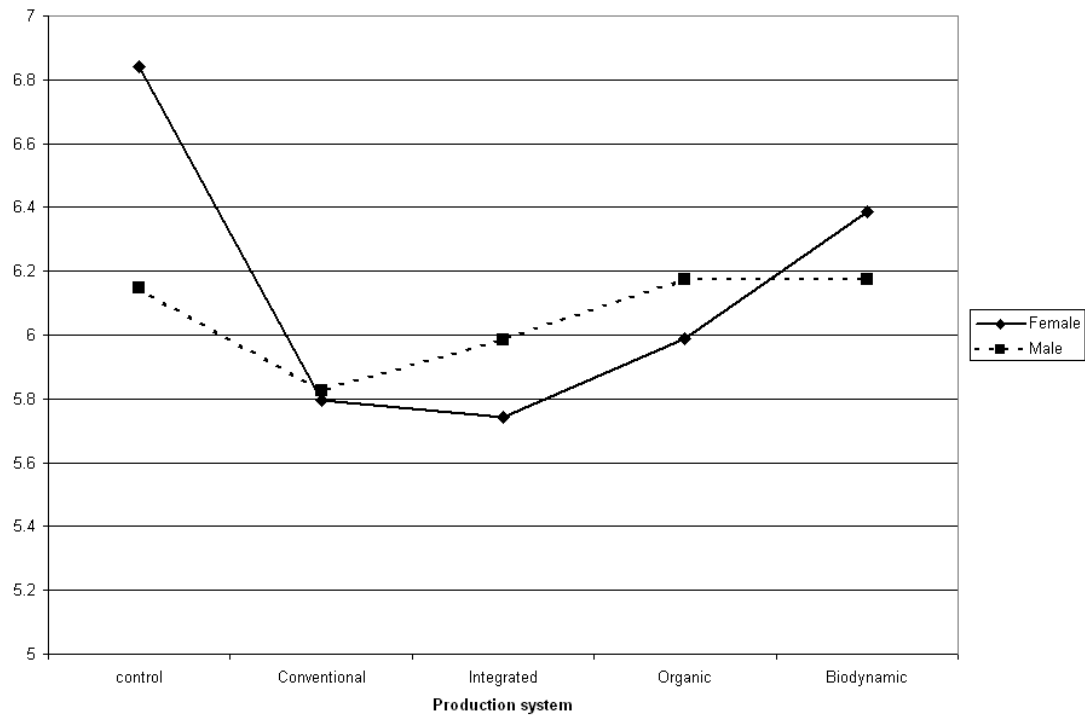


Figure 4.8. Color of red beet depending on production system and sex of evaluator

According to the correlation analysis (Table 4.5), the strongest correlation was observed between taste and willingness to buy in both white cabbage ($r=0.871$) and red beet ($r=0.874$), followed by odor and color. This is in line with findings of other authors (Wszelaki et al. 2005), who discovered that taste is the most determining of the sensory qualities regarding consumers' willingness to purchase food.

Table 4.5. Pearson's correlation coefficients for the evaluated attributes of white cabbage and red beet in two successive years

White cabbage	Odor	Taste	Willingness to buy
Color	0.585**	0.548**	0.681**
Odor		0.635**	0.725**
Taste			0.871**
Red beet			
Color	0.577**	0.535**	0.684**
Odor		0.654**	0.753**
Taste			0.874**

Levels of significance: ** ≤ 0.01 .

Having in mind that the majority of organic food consumers in the EU (Davies et al. 1995) or other countries (Cunningham 2004) are represented by women aged 25 to 40 (which was also the largest age group in our study amounting to over 40 percent of all participants), our results indicate one of the possible reasons consumers opt to buy organic food (next to personal health care and care for the environment (Bourn and Prescott 2002; Yiridoe et al. 2005)). Women have sharper senses (Theurer 2006), and as such, they are usually in charge of buying food for the whole family. In addition, women with children more often tend to choose organically produced food (Davies et al. 1995). In this sense, the color, odor, and taste of it, along with other factors, play an important role in the decision-making process—especially if the decision maker is a better taster and the food he/she chooses tends to be tastier (Bourn and Prescott 2002; Rembialkowska 2007). This hypothesis was confirmed in this study for red beet produced in two successive years. For white cabbage, however, it was not confirmed, as contrasting results were attained in the two successive production years.

4.4 Conclusions

It was observed in the present study that production system, production year, and sex of evaluators had an impact on sensory perception of white cabbage and red beet, where most of the variability of the results can be ascribed to production systems. On average, INT and control cabbage samples were scored higher than ORG, BD, and CON samples. On the contrary, control and BD samples of red beet were evaluated higher in most attributes than CON samples, with the ORG and INT systems in-between. The acceptance of red beet for female evaluators points towards one of the possible reasons why the organic consumer prefers ORG and BD foods to CON and INT foods, although this was not confirmed for white cabbage.

It is also important to keep in mind that there is sometimes variation within the different alternative production systems in the same range as between alternative and industrial production systems. This makes it difficult to draw categorical conclusions regarding sensory food quality, and therefore, different production systems from the “organic” and

“conventional” range have to be compared separately. The findings of this study also point to the challenges and pitfalls of comparing production systems based on only one year’s produce of one single crop, as the sensory quality can vary, depending on soil and weather conditions even in a controlled field trial, which was visible in the case of white cabbage. When harvesting, shipping, handling, and marketing variables are added to the comparison, findings regarding quality of food become even more complex and relative. Thus, we emphasize the need to compare the effects of farming systems on food quality in samples originating from controlled field trials in order to eliminate as many other variables as possible.

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5 Influence of industrial and alternative farming systems on contents of sugars, organic acids, total phenolic content and the antioxidant activity of red beet (*Beta vulgaris* L. ssp. *vulgaris* 'Rote Kugel')

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Abstract

The contents of sugars, organic acids, total phenolic content and the antioxidant activity were quantified in the flesh of red beet from conventional (CON), integrated (INT), organic (ORG), biodynamic (BD) and control farming systems using established methods. Significant differences were measured for malic acid, total phenolic content (TPC) and total antioxidant activity, where malic acid content ranged from 2.39 g kg⁻¹ FW (control) to 1.63 g kg⁻¹ FW (CON, ORG and INT). Highest TPC was measured in BD and control samples (0.677 and 0.672 mg GAE g⁻¹, respectively), lowest in CON samples (0.511 mg GAE g⁻¹). Antioxidant activity was positively correlated with TPC ($r^2=0.6187$) and ranged from 0.823 µM TE g⁻¹ FW to 1.270 µM TE g⁻¹ FW in CON and BD samples, respectively, whereas total sugar content ranged from 21.03 g kg⁻¹ FW (CON) to 31.58 g kg⁻¹ FW (BD). The importance of sugars, organic acids, phenols and antioxidants for human health, as well as for plant resilience and health, gained from this explorative study, is discussed and put into perspective.

Keywords:

Beta vulgaris; red beet; organic farming; biodynamic farming; quality of food; farming system comparison; chemical composition; sugars; organic acids; total phenolic content; antioxidant activity

5.1 Introduction

In recent times there is increased interest in the influence of farming systems on food quality, especially regarding the composition and health promoting effects of food (Reganold et al. 2010). The methods of industrial farming are ever more subjected to public pressure for their environmental and health effects (Wackernagel and Rees 1995). Alternatives have been sought, and an integrated approach towards agricultural production has been created (Bavec et al. 2009). Moreover, demand for organically grown products is steadily growing and has exceeded supply in many countries (Bavec et al. 2009). Consumer and research interest in the biodynamic farming system, which is regarded as a part of the organic farming movement, is posing questions regarding its influences and differences (Turinek et al. 2009). A number of studies comparing organically and conventionally produced food have been conducted over the past 20 years, the results of which are summarized in various review papers (Worthington 2001; Bourn and Prescott 2002; Rembialkowska 2007; Velimirov et al. 2010). Findings point towards the trend that organically produced foodstuffs in most cases contain greater amounts of health promoting constituents (e.g. vitamins, phenols) and lesser amounts of harmful constituents (e.g. pesticide residues, nitrates). However, results are not always consistent, as there is a great variety of environmental and production factors influencing the composition of food. Different approaches towards sampling also influence the comparison of food from different farming systems. Often food is bought in the store or from the market and then the composition is compared (Bourn and Prescott 2002). This presents one of the easiest methods for acquiring samples and, at the same time, it is the food that the consumer would eventually buy in the store or from the market. However, the influence of handling, transport, refrigeration and/or shelf life is not always given and is difficult to account for. Sampling different crop varieties can also bias the results strongly.

Another approach would be to find matching pairs of farms with a different production systems in close proximity to each other. In this case environmental and soil conditions are better matched between the samples and similar varieties can be grown. One also has a better overview of the production methods and treatments used. However, it is hard to compare more than two different production systems (i.e. four), as so many different farms

are often not in close proximity. It is also a challenge to control soil tillage, sowing and harvesting dates, as practices differ with every farmer.

A controlled field trial is the third option, where most of the above mentioned factors can be either controlled or at least recorded, and where the same varieties and sowing/harvesting dates are applied in all systems under study. The drawback of such trials lies in the cost of establishing and running them. Plots also have to be large enough to gather practice relevant results and at the same time be manageable within a trial.

Furthermore, the greater number of studies comparing vegetables from organic and conventional production has focused mainly on cabbage, carrots, tomatoes and potatoes (Lairon 2010), whereas other vegetable crops have been examined more sporadically. In the only study found, comparing red beet from organic and conventional production, yields, holistic quality and some internal quality parameters were investigated (Mäder et al. 1993). Red beet is regarded as a good potential source of antioxidants and phenols (Pellegrini et al. 2003; Gliszczyńska-Swigło et al. 2006; Mattila and Hellström 2007; Kugler et al. 2007; Pradhan et al. 2010), and it also expresses anticancer and radio-protective properties (Sembries et al. 2006; Lu et al. 2009). It has also been shown to contain other health promoting constituents (Hansen 1980; Rodríguez-Sevilla et al. 1999; Bandyopadhyay et al. 2008) and is therefore regarded as a good enrichment of the human diet (Hernandes et al. 2007). Furthermore, to date no studies have been published that investigate differences due to the production method in the contents of sugars, organic acids, total phenolic content and the antioxidative activity in red beet. Thus, there is a need for more studies comparing the amounts of these substances in plant foods under well-defined conditions.

The main objectives of this study were, therefore, to (1) produce red beet in four different production systems (+ control plots) in a controlled field trial, (2) collect representative samples of red beet roots and (3) analyze the chemical composition (sugar, organic acid, total phenolic content and the antioxidative activity) of red beet from the different farming systems under study.

5.2 Material and methods

5.2.1 Chemicals

The following standards were used for the quantification of sugars and organic acids: sucrose, glucose and fructose; and citric, fumaric, malic and shikimic acids from Sigma-Aldrich Chemie GmbH (Steinheim, Germany). The chemicals for the mobile phase were HPLC grade. For the total phenolic content, Folin-Ciocalteu phenol reagent (Fluka Chemie GmbH, Buchs, Switzerland), sodium carbonate (Merck, Darmstadt, Germany), gallic acid and ethanol (Sigma-Aldrich) were used. For the antioxidant activity 1,1-Diphenyl-2-picrylhydrazyl (DPPH), ascorbic acid and methanol were purchased from Sigma-Aldrich.

5.2.2 Plant material

The plant material was produced in a long-term field trial 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.). Four production systems + control plots were arranged in a randomized complete block split-plot design with four replications. The size of the experimental field plots was 7m×10m, with 4 m buffer zones between production systems. The farming systems differed mostly in plant protection and fertilization strategies and are defined by the valid legislation and standards – conventional (CON) (MKGP 2008), integrated (INT) (MKGP 2002, 2004, 2008), organic (ORG) (EC 834/2007 2007; MKGP 2008), biodynamic (BD) (EC 834/2007 2007; MKGP 2008; Demeter International e.V. 2009) farming system and control (MKGP 2008) 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 5.1). Differences in fertilization and plant protection are presented in detail in Table 5.2. Two different five-course crop rotations were used, where red beet was preceded by 2 years of red clover-grass and spelt, and was succeeded by false flax. 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.

The same varieties of crops were used in all farming systems, although the origin of the seed differed – organically produced seed for the ORG, BD and control plots vs. conventionally produced seed for CON and INT plots. The red beet variety Rote Kugel was chosen, as it is a quality variety for fresh consumption and processing, and its seed was the only one available in both CON and ORG origin.

Table 5.1. Farming systems under investigation in the field trial and differences between them

Production system	Soil cultivation and basic operations	Weed management	Pest management	Manure application
Conventional farming according to the Slovene agriculture act and GAP	Plowing, 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 according to Slovene standards for Integrated farming	Plowing, 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 according to the EC regulation on Organic Farming	Plowing, seedbed preparation, sowing, harvesting	Harrowing 2-5 times/season, cover crops after cereals	Use of some natural pesticides (Neem-oil, BT extract) on vegetable crops when needed	1.4 LU of cattle manure /ha
Biodynamic farming according to Demeter International production standards and EC regulation on Organic Farming	Plowing, seedbed preparation, sowing, harvesting	Harrowing 2-5 times/season, cover crops after cereals	Use of BD preparations, some natural pesticides (Neem-oil, BT extract) on vegetable crops when needed	1.4 LU of composted cattle manure /ha with added BD compost preparations
Control plots	Plowing, seedbed preparation, sowing, harvesting	Harrowing 1-3 times/season	none	none

GAP – good agricultural practice; INT – integrated farming; EC – Council regulation 834/2007; BT – *Bacillus thuringiensis*; LU – livestock units; BD – biodynamic

Samples of red beet were picked on 19th August 2009 from the centre 10m² of the experimental plots, cleaned and samples from each plot stored separately at optimal conditions (Henze and Baumann 1979) in a cooling room at 6 °C and 95% relative humidity until the analyses were performed. Sample preparation for analyses was done on 4th November 2009. For the analyses 5 representative roots were taken from each stored plot/replication.

5.2.3 Analysis of individual carbohydrates and organic acids

Red beet samples were analyzed for their content levels of carbohydrates (sucrose, glucose and fructose) and organic acids (malic, citric, succinic and fumaric). In the laboratory, roots for each sample were peeled, halved, cut into small pieces and thoroughly mixed. Thereafter 5 g of the fresh mass was immersed in 15 mL of twice distilled water and homogenized with a T-25 Ultra-Turrax (Ika-Labortechnik, Stauden, Germany). The vegetable samples were left for extraction for half an hour at room temperature, with frequent stirring, and the extracted samples were centrifuged at 15 550 g for 7 minutes at 10 °C (Eppendorf Centrifuge 5810R, Hamburg, Germany). The supernatants were filtered through a 0.45 µm filter (Macherey-Nagel, Düren, Germany), transferred to a vial, and analyzed according to the method described by Sturm, Koron and Stampar (2003) using high-performance liquid chromatography (HPLC; Thermo Scientific, Finnigan Spectra System, Waltham, MA, USA). For each analysis, 20 µL of sample was used. Analysis of sugars was carried out using a Rezex-RCM-monosaccharide column (300 × 7.8 mm; Phenomenex, Torrance, CA), and RI detector with a flow of 0.6 mL min⁻¹ and with column temperature maintained at 65 °C. For the mobile phase, twice distilled water was used, and an RI detector for identification. Organic acids were analyzed using a Rezex-ROA-organic acid column (300 × 7.8 mm; Phenomenex, Torrance, CA), and the UV detector set at 210 nm with a flow of 0.6 mL min⁻¹ maintaining the column temperature at 65 °C. For the mobile phase, 4 mM sulfuric acid (H₂SO₄) was used. The concentrations of carbohydrates and organic acids were calculated with the help of corresponding external standards.

Table 5.2. Plant protection and fertilizer applications for red beet (*Beta vulgaris* L. ssp. *vulgaris* 'Rote Kugel') production in the year 2009

Production system	Plant protection applied	Fertilizers applied (time of application)	Amounts of nutrients applied					
			N (kg/ha)	N (CON=100%)	P (kg/ha)	P (CON=100%)	K (kg/ha)	K (CON= 100%)
Conventional farming	-Herbicides: - Goltix (4 kg/ha) - Fusilade forte (1.5l/ha) - Beetup compact (3l/ha) - Agil (1l/ha) -Fungicides: - Amistar Extra (0.8l/ha) -Insecticides: - Bulldock (0.5l/ha)	- 350 kg/ha NPK fertilizer 7:20:30 (before sowing) - 325 kg/ha Potassium salt (60% K) (before sowing) - 270 kg/ha CAN fertilizer (27% N) (2 rates 1 month apart)	124.5	100	70	100	300	100
Integrated farming	-Herbicides: - Goltix (4 kg/ha) - Fusilade forte (1.5l/ha) - Beetup compact (3l/ha) - Agil (1l/ha) -Fungicides: - Amistar Extra (0.8l/ha) -Insecticides: - Bulldock (0.5l/ha)	- 200 kg/ha NPK fertilizer 15:15:15 (before sowing) - 450 kg/ha Potassium salt (60% K) (before sowing) - 270 kg/ha CAN fertilizer (27% N) (2 rates 1 month apart)	130	104	30	43	300	100
Organic farming		- 21,450 kg/ha of cattle manure ¹ (before plowing in autumn)	106	85	36	51	162	54
Biodynamic farming	BD preparations 500, 501, 507	- 18,000 kg/ha of composted cattle manure ¹ with BD preparations 502-507 added (before plowing in autumn)	112	90	57	81	45	15
Control plots	/	/	0	0	0	0	0	0

N – nitrogen; P – phosphorus; K – potassium; CON – conventional farming, BD – biodynamic; ¹ – cattle manure and composted cattle manure were analyzed for their contents of NPK before application

5.2.4 Determination of total phenolic content

In the laboratory, roots for each sample were peeled, halved, cut into small pieces and thoroughly mixed. Five grams of each sample was extracted with methanol (10 ml) and homogenized with the T-25 Ultra-Turrax, then sonicated with a Sonis 4 (Iskra pio, Ljubljana, Slovenia) for 1 h in a cooled water bath. After extraction, the sample extracts were centrifuged for 10 min at 15 550 g at 4 °C. The supernatant was filtered through a Chromafil AO-45/25 polyamide filter (Macherey-Nagel, Düren, Germany) and transferred to a vial.

The total phenolic content (TPC) of the extracts was assessed using the Folin-Ciocalteu phenol reagent method (Singleton and Rossi 1965). Six ml of twice-distilled water and 500 µl of Folin-Ciocalteu reagent were added to 100 µl of the sample extracts and after waiting for between 8 s and 8 min at room temperature, 1.5 ml of sodium carbonate (20% w/v) and 1.9 ml twice-distilled water was added. The extracts were mixed and allowed to stand for 30 min at 40 °C before measuring absorbance at 765 nm on a Lambda Bio 20 UV/VIS spectrophotometer (Perkin Elmer, Waltham, MA). A mixture of water and reagents was used as a blank. The total phenolic content was expressed as gallic acid equivalents (GAE) in mg per g FW of red beet. Absorptions were measured in three replicates.

5.2.5 Determination of antioxidant activity by the DPPH radical scavenging method

Samples for the determination of antioxidant activity were prepared using the same method as for TPC. The free radical scavenging activity of the red beet extracts was measured according to the DPPH (1,1-diphenil-2-picrylhydrazyl) method reported by Brand-Williams, Cuvelier & Berset (1995), with slight modifications. Extract (50 µl) was placed in 96-well microplates, and 200 µl of 0.1 mM methanolic solution of DPPH was added and allowed to react in the dark at room temperature. The decrease in absorbance of DPPH at 520 nm was measured at 5 min intervals by a spectrophotometer (Perkin Elmer, Waltham, MA), until the absorbance stabilized (30 min). Methanol was used as a blank and DPPH solution without sample as a control. All samples were prepared in triplicate.

Determination of antioxidant activity of the samples at various concentrations was made using the trolox standard curve. The DPPH radical scavenging activity of red beet extracts was expressed as μM trolox equivalents (TE) per g FW of red beet.

5.2.6 Statistical design and methods

Data were analyzed by one-way ANOVA with production system as a factor using Statgraphics Centurion (Version XV, StatPoint Technologies, Inc., Warrenton, VA). This was followed by least squares means comparisons after Duncan (Hoshmand 2006). Values given within the paper are means $\pm$ standard error of mean (SEM).

5.3 Results and discussion

5.3.1 Sugars

The same variety of red beet from five different production systems (control, CON, INT, ORG and BD) was examined in this study and the concentrations of individual sugars were assessed. The most abundant sugar in red beet was found to be sucrose, whereas fructose and glucose were found only in small amounts (Table 5.3). This corresponds with the findings of Rodríguez-Sevilla et al. (1999), where sucrose was also found to be the most abundant sugar in raw red beet samples. Values for the total sugar content ranged from 21.03 g kg^{-1} (CON) to 31.58 g kg^{-1} (BD), whereas no statistically significant differences were found between the farming systems. Nevertheless, a trend of more total sugar content in organic farming systems is observable. Maeder et al. (1993) compared red beet from different farming systems on the basis of sucrose content and reported no differences between the farming systems. However, also no account is given on the measured values. The importance of sugar content in vegetables is gaining increasing interest, as sugars constitute the main energy source in vegetarian diets (Rodríguez-Sevilla et al. 1999) and information on the content of carbohydrates of food is of relevance also for diabetic patients, as they need to adapt insulin dosage accordingly (Hecke et al. 2006). In addition, sugar is being intensively researched for its sensing and signaling functions in plant physiology and development, and it was found to be integrated with signaling pathways in

plants (for inorganic nutrients, hormones and various stress factors) (Hanson and Smeekens 2009).

Table 5.3. Concentrations of individual sugars in tubers of red beet (*B. vulgaris* L. cv. Rote Kugel) depending on farming system in g kg⁻¹ FW

Farming system	Sucrose	Glucose	Fructose	Total sugar
Control	28.45 ± 7.36	0.28 ± 0.14	1.10 ± 0.21	29.83 ± 7.16
Conventional	18.88 ± 4.85	0.65 ± 0.20	1.49 ± 0.19	21.03 ± 4.66
Integrated	24.87 ± 2.63	0.80 ± 0.35	1.33 ± 0.19	27.01 ± 2.95
Organic	23.70 ± 5.28	0.76 ± 0.17	1.55 ± 0.15	26.01 ± 5.34
Biodynamic	29.26 ± 3.66	0.95 ± 0.39	1.37 ± 0.20	31.58 ± 3.49

Average values ± standard errors are presented. No statistically significant differences were detected between the farming systems.

5.3.2 Organic acids

Four organic acids were identified in red beet, namely: citric, malic, shikimic and fumaric acid (Table 5.4). Shikimic acid was the most abundant organic acid. Statistically significant differences were found between different farming systems for malic acid content. Significantly highest values were measured in samples from control plots, followed by the BD samples. The CON, INT and ORG samples contained significantly lower amounts of this organic acid compared to the samples from control plots. Results are partly in line with findings from previous studies, where higher values of malic acid were measured in maize and blueberries from organic production (Wang et al. 2008; Röhligh and Engel 2010).

A study of Rudrappa et al. (2008) hints towards one of the possible reasons for this phenomenon. It was demonstrated that malic acid, selectively excreted through roots, signals beneficial rhizobacteria and encourages their interaction with plants. Beneficial soil bacteria have been found to confer immunity against a wide range of foliar diseases by activating plant defenses. Organic acids (as well as phenolic compounds) have been also found to participate in leveling out P deficiency by being excreted through plant roots (Badri and Vivanco 2009). Levels of P added in our trial were similar for the INT and ORG systems and CON and BD systems (Table 5.2), whereas control plots received no

additional P. The aforementioned potential role of organic acids and phenolic compounds in leveling out P deficiency is thus partly reflected in the malic acid concentrations and the TPC in our trial.

Table 5.4. Concentrations of organic acids in tubers of red beet (*B. vulgaris* L. cv. Rote Kugel) depending on farming system

Farming system	Citric acid	Fumaric acid	Malic acid		Shikimic acid	Total organic acid
	mg kg ⁻¹ FW		g kg ⁻¹ FW			
Control	290.07 ± 65.38	0.21 ± 0.13	2.39 ± 0.36	a	36.75 ± 6.77	39.43 ± 6.47
Conventional	304.44 ± 62.16	0.46 ± 0.21	1.63 ± 0.07	b	25.03 ± 8.19	26.96 ± 8.21
Integrated	311.71 ± 79.34	0.54 ± 0.07	1.63 ± 0.08	b	13.76 ± 1.00	15.70 ± 1.08
Organic	218.41 ± 6.03	0.33 ± 0.10	1.63 ± 0.21	b	24.13 ± 10.74	25.98 ± 10.92
Biodynamic	322.01 ± 3.59	0.58 ± 0.28	2.03 ± 0.11	ab	24.81 ± 8.88	27.05 ± 8.98

Average values ± standard errors are presented. Different letters (a-b) in rows mean statistically significant differences between the farming systems at $p < 0.05$ (Duncan test).

However, the BD system deviates from this assumption in both cases – despite relatively high levels of P added also high values for malic acid and TPC were measured. Reasons for this deviation could be sought in a changed microbial structure, enzyme activity or amino acid metabolism found in BD systems (Turinek et al. 2009). The levels of potassium (K) added correspond better with the measured values of malic acid and TPC, for control and BD plots received substantially less K than CON, INT and ORG plots (Table 5.2). However, results are in contrast to findings of Lobit et al. (2006), who modeled malic acid accumulation and suggest, that there is a strong positive effect of K on malic acid accumulation at the maturity stages of fruits. Levels of N added were similar in all production systems (except control) and are thus a less plausible explanation for the varying organic acid levels. Moreover, according to the carbon:nutrient balance hypothesis (Lerdau and Coley 2002), reasons for a higher content of shikimic acid in some samples could be linked to lower nutrient availability, especially in the control system. However, results for the other systems under investigation are not consistent with this explanation of limited nutrient availability, and perhaps a more complex mechanism would better explain

the differences. Plant-microbial interactions and plant-soil interactions are increasingly being researched and seem to play an important role in providing plants with nutrients and activating resilience against pests and diseases, where as a consequence food products can also gain some beneficial constituents/compounds (Badri and Vivanco 2009). Reganold et al. (2010) found more than 200 different unique strains of microorganisms in organic soils, as compared to only 2 in conventional soils for strawberry production.

5.3.3 Total phenolic content

TPC of red beet samples ranged from 0.51 mg g⁻¹ FW GAE to 0.68 mg g⁻¹ FW GAE in CON and BD beet, respectively. Samples from BD and control plots had significantly higher TPC than samples from CON plots (Figure 5.1). The importance of polyphenols as secondary plant metabolites is still under discussion. Some authors have demonstrated their anticarcinogenic activity (Owen et al. 2000; IUBMB and Fraga 2009) others their potential as an atherosclerosis drug (Noguchi and Niki 2000). They have been also shown to play a role in plant defense mechanisms (Veberic et al. 2005; Mikulic Petkovsek et al. 2009) as well as in the antioxidant activity of the plant (Veberic et al. 2005). However, the effect of polyphenols strongly depends on the type of polyphenol and its combination with other compounds. It is therefore difficult to draw any definite conclusions on health effects of total polyphenol content on humans on the basis of TPC. A more detailed composition analysis of TPC would be of assistance, this was, however, not within the scope of this research paper.

Kujala et al. (2000) report that the TPC of red beet samples decreases in the order peel>crown>flesh. Values measured in their studies ranged from 15.5 mg g⁻¹ in the peel to 4.2 mg g⁻¹ in the flesh (dry weight). When we compare these with regards to the dry matter (DM) content of red beet in our trial, where values of TPC lie between 3.16 mg g⁻¹ DM GAE (CON) and 4.94 mg g⁻¹ DM GAE (control), results are in a similar range to previous findings (45), since we determined TPC only in the flesh of the beets. We also have to consider that the quality deterioration of red beet roots in storage, although stored at optimal conditions, can be expressed in significantly lower TPC values over time (Kujala et al. 2000). The roots in our trial were in storage for 2 months.

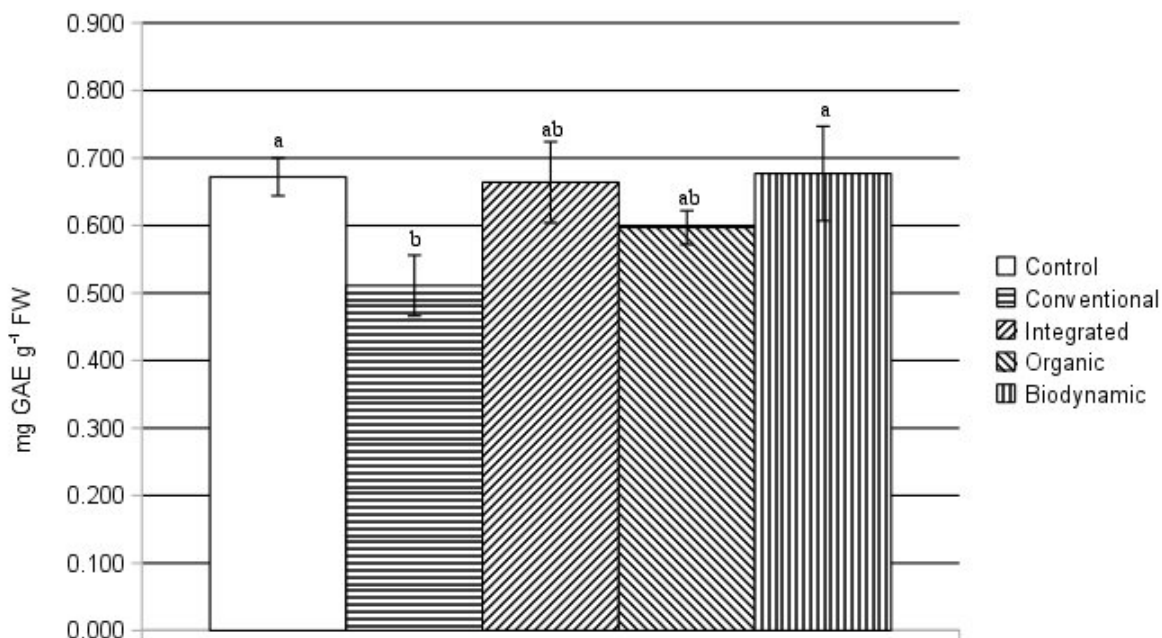


Figure 5.1. Total phenolic content of red beet depending on farming system expressed as gallic acid equivalents (GAE) in mg g⁻¹ FW of red beet. Average values $\pm$ standard errors are depicted. Different letters (a-b) above bars mean statistically significant differences in total phenolic content between the farming systems at $p < 0.05$ (Duncan test).

5.3.4 Antioxidant activity

The antioxidant activity, expressed as Trolox equivalents (TE), ranged from 0.823 $\mu\text{M TE g}^{-1}$ FW to 1.270 $\mu\text{M TE g}^{-1}$ FW in CON and BD samples of red beet, respectively (Figure 5.2). Kugler et al. (2007) reported higher values for the antioxidant activity of red beet (11.103 $\mu\text{M TE g}^{-1}$), where freshly picked red beet roots of the same variety as in our study were extracted and analyzed. Also Pellegrini et al. (2003) reported higher values (5.21 $\mu\text{M TE g}^{-1}$) for red beet samples purchased at a supermarket. However, differences in attained values could be attributed to the different focus of the studies, as our interest lies in results given on a FW basis, rather than on DM basis. If we include the DM content in the final results, values lie in a similar range to findings of aforementioned studies (from 5.09 $\mu\text{M TE g}^{-1}$ in CON to 9.05 $\mu\text{M TE g}^{-1}$ in control samples).

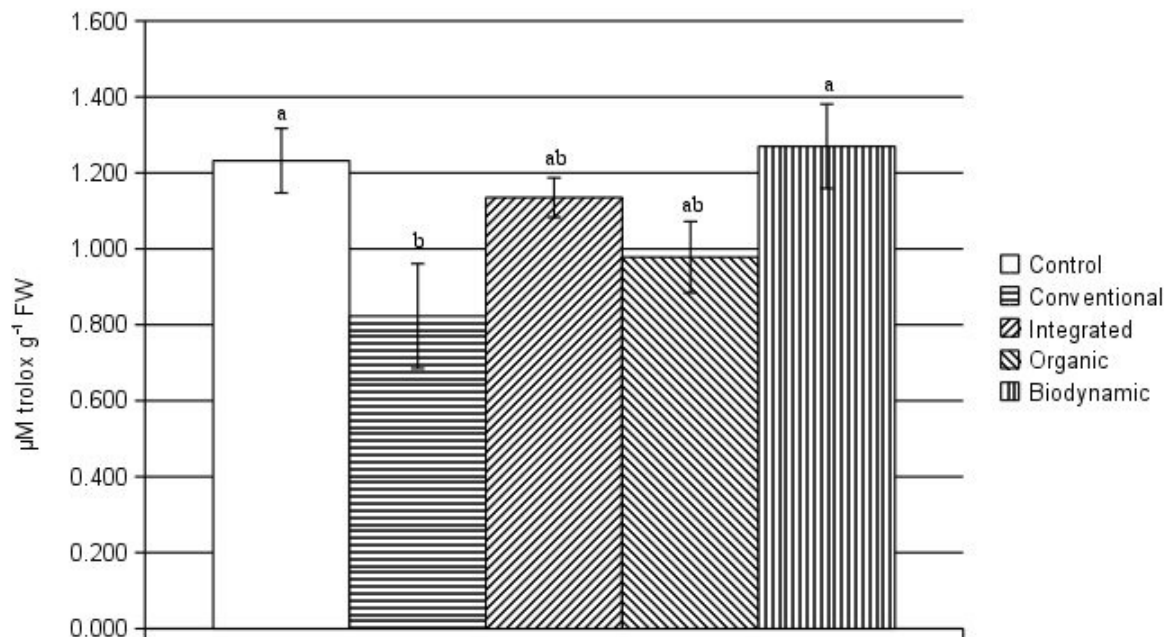


Figure 5.2. Antioxidative activity of red beet depending on farming system expressed as µM Trolox equivalents per g FW of red beet. Average values ± standard errors are depicted. Different letters (a-b) above bars mean statistically significant differences in antioxidative activity between the farming systems at $p < 0.05$ (Duncan test).

Samples from BD and control plots had significantly higher TE values than samples from CON plots (Figure 5.2). Furthermore, there is a significantly positive linear correlation between the TPC content and antioxidant activity ($r^2=0.6187$). This is in line with findings from other authors (Kugler et al. 2007). However, one has to bear in mind that phenolic substances are not the only influence on the antioxidant activity of beetroot. Close and McArthur (2002) suggest, that phenolic content and antioxidant activity increases under conditions with high light or limited fertilization, in order to prevent photodamage to plants. When taking into account nutrients added to the farming systems under investigation (Table 5.2), this theory could partly explain the higher values measured in the alternative farming systems.

In conclusion we can affirm our assumption, that differences between farming systems do exist, even if sometimes only a trend is noticeable. What we could also observe was a variability in the results for some parameters, which may be attributed to the micro

variability of soil and/or climatic conditions (as other factors were controlled: fertilization, plant protection, soil cultivation), since the plots and the whole experimental area amounts to over 1 ha. However, this resembles field conditions in practice, where sometimes neighboring fields may have varying soil/climatic conditions and consequently also varying product quality. Despite this consideration, statistically significant differences were measured for malic acid, TPC and antioxidant activity values, where red beet from the control production system expressed significantly highest values, followed by BD, INT and ORG systems, whereas significantly lower values were measured for red beet from the CON production system. It is also important to keep in mind, that sometimes there is a variation within the different organic production systems in the same range as between organic and conventional production systems. This makes it difficult to draw categorical conclusions regarding food quality and therefore different production systems from the “organic” and “conventional” range have to be compared separately. Measurements done on one variety in one production year may also be regarded as of a more explorative nature, however, long-term trials comparing more varieties and production systems of many different crops are, as discussed already at the beginning of the paper, highly time-, work- and resource-intensive, especially when all analyses following the trial and the gap between individual crops within the crop rotation are taken into account. Therefore we believe that it is important to share and publish results of controlled field trials on a regular basis, in order to update the common base of scientific knowledge in this highly interesting area of production systems comparisons.

Because our interest in the contents of sugars, organic acids, TPC and the antioxidant activity of red beet roots was focused on the consumer, the removal of the peel may have decreased the content of some constituents, especially when comparing the TPC and antioxidant activity values with other studies. However, results are of relevance to practice, since few people, if any, eat unpeeled red beet roots. Furthermore, many vegetarians, vegans and also omnivores consume red beets fresh in salads. Additionally, storage times of 2-3 months used in this study partly take into account quality changes due to storage. Examining the effect of longer storage times and processing procedures on red beet roots from different production systems, however, is seen as a future challenge and would additionally clarify the importance of production systems on the quality of food.

5.4 References

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6 Povzetek

Biološko-dinamično (BD) kmetijstvo je leta 1924 predlagal Steiner v sklopu osmih predavanj, imenovanih »Kmetijski tečaj«, in je danes eden izmed ekoloških (EKO) načinov kmetovanja. BD metoda kmetovanja stremi k pestrim, odpornim in vedno se razvijajočim kmetijam, ki bi lahko zagotovile ekološko, ekonomsko in fizično trajnost za človeštvo. Vključuje prakse kompostiranja, mešanih kmetij z uporabo živalskih gnojil, kolobarjenje, skrb za dobrobit živali, dojemanje kmetije kot organizma/celote in lokalne prehranske sisteme. Vse našteto pa prispeva k varovanju okolja, ohranitvi biotske pestrosti in k izboljšanju življenja kmetov. Dandanes obstaja več kot 4.200 BD kmetij v več kot 43 državah, katerih površina znaša preko 128.000 hektarjev in je certificirana v skladu z Demeter standardi. Poleg pravil, ki veljajo v EKO kmetijstvu, Demeter smernice zahtevajo uporabo BD pripravkov, obvezno rejo živali, uporabo živalskih gnojil v obliki komposta in močno vzpodbujajo lokalne pridelovalne ter distribucijske sisteme z uporabo lokalnih pasem in sort. Prav tako so sprejete stroge smernice za predelavo. BD metoda poudarja celostni pristop h kmetijstvu in je postala predmet raziskav v zadnjih desetletjih, ko je bilo obravnavano mnogo vprašanj glede BD kmetijstva in so bili izsledki raziskav objavljeni v le okoli 30 recenziranih znanstvenih člankih. V tem smislu BD sistem predstavlja uspešno metodo kmetovanja, ki jo je smiselno podrobneje raziskovati.

V ta namen je bil leta 2007 postavljen poljski poskus, ki je lociran na Univerzitetnem kmetijskem centru Fakultete za kmetijstvo in biosistemske vede Univerze v Mariboru v Pivoli blizu Hoč (46°28'S, 15°38'V, 282 m nmv.). Za potrebe poskusa je bilo zasnovanih šestdeset 7×10 m velikih parcel, ki so oskrbovane in obdelovane znotraj dveh različnih zasnov kolobarjev. V enem kolobarju so tipične rastline za to območje (2 leti deteljno travne mešanice, pšenica, zelje, oljne buče), drugi pa je zasnovan kot alternativni kolobar (2 leti deteljno travne mešanice, pira, rdeča pesa, oljni riček). 2 leti pred pričetkom poskusa je na poskusnem polju rasla deteljno-travna mešanica. Celotno poskusno polje je bilo 6 let pred pričetkom poskusa oskrbovano v skladu s standardi za EKO kmetijstvo. Štiri pridelovalni sistemi (konvencionalni (KON), integrirani (INT), EKO in BD) ter kontrolni sistem (brez gnojenja in varstva rastlin) so bili razporejeni v naključnem blok sistemu s

»split-plot« razdelitvijo parcel v štirih ponovitvah. Pridelovalni sistemi so se večinoma razlikovali v varstvu rastlin in gnojenju ter so definirani preko veljavne zakonodaje, uredb in privatnih standardov. Osnovna obdelava tal, setev in spravilo pridelkov, se po metodah in datumih niso razlikovali med sistemi. Prav tako so bile v vseh pridelovalnih sistemih uporabljene iste sorte posamezne kmetijske rastline (pšenica "Antonius", pira "Ebners Rotkorn", zelje "Kranjsko okroglo", rdeča pesa "Rote Kugel", buče "Gleisdorfska golica" in oljni riček "Koroški avtohtoni"), ki pa so se razlikovale v izvoru – konvencionalno pridelano za KON in INT parcele in EKO pridelano za EKO, BD in kontrolne parcele. Letna povprečna temperatura zraka na tem območju je 10,7 °C, kjer je povprečni mesečni minimum v januarju (0,4 °C), maksimum pa v juliju (20,8 °C). Povprečna letna količina padavin na območju poskusa je okoli 1000 mm.

Namen in cilji poskusa so bili razdeljeni v več delov/raziskav, iz katerih je tudi sestavljen doktorat. Tako smo v (i) delu primerjali pridelke, agronomsko učinkovitost (AU) glede na pridelke pri nekaterih poljščinah (pšenica, zelje, oljne buče) v treh letih in populacijo ter biomaso deževnikov v dveh letih pri prej omenjenih poljščinah. V ta namen smo izmerili in določili dodana hranila v času trajanja poskusa in nato analizirali zbrane podatke in primerjali pridelovalne sisteme med seboj. V (ii) raziskavi smo se posvetili področju okoljskega odtisa, z vključeno določitvijo življenjskega cikla (LCA – life-cycle assessment), ki je še vedno v fazi razvoja za uporabo v kmetijstvu. Za potrebe raziskave smo pomagali dodatno razviti in nato uporabili Sustainable Process Index® (SPI), ki ga je ustvarila Tehniška univerza v Gradcu. Metodologija SPI-ja je bila prilagojena za kmetijstvo. Uporabili smo triletno podatke iz poljskega primerjalnega poskusa za pridelavo pšenice in pire, zato tudi rezultati odsevajo razmere v resničnih situacijah in pridelovalnih sistemih. Osnovno vprašanje, ki smo si ga zastavili je bilo, kako trajnostni so pridelovalni sistemi, ki se jih v največji meri uporablja danes, in kje jih je možno izboljšati, da bi povečali trajnostno pridelavo hrane za prihodnje generacije. Kot primer smo naredili projekcijo pridelave pšenice in pire v Sloveniji. V tretji raziskavi pa nas je zanimalo (iii), če je možno zaznati kakšne razlike med industrijskimi in alternativnimi pridelovalnimi sistemi v večji skupini potrošnikov. V ta namen smo raziskali senzorične lastnosti zelja in rdeče pese v dveh zaporednih letih (2008 in 2009), vzorce katerih sta ocenili dve skupini

potrošnikov. Po našem vedenju podobne raziskave, kjer bi primerjali senzorične lastnosti zelja in rdeče pese v raziskovanih štirih pridelovalnih sistemih, še ni bilo narejene. Zato smo primerjali rezultate ocen med pridelovalnimi sistemi, med leti in med spoloma. Primerjave notranje kakovosti rdeče pese iz različnih pridelovalnih sistemov so zelo redke, čeprav se rdeča pesa smatra kot potencialen vir antioksidantov in fenolov, izkazuje protirakavo in zaščitno delovanje proti sevanju ter vsebuje druge zdravju koristne sestavine. Tako je bil glavni cilj (iv) raziskave pobrati pridelek reprezentativnih vzorcev rdeče pese in analizirati njihovo kemijsko sestavo (sladkorje, organske kisline, skupne fenole in antioksidativno aktivnost) ter na osnovi opravljenih analiz narediti temeljito primerjavo vpliva pridelovalnih sistemov.

(i) Pridelki pšenice so se razlikovali med pridelovalnimi sistemi in leti. Najvišji pridelki so bili doseženi v KON sistemu (4.263 kg ha^{-1}), najnižji pa v kontroli in EKO sistemu (2.467 in 2.450 kg ha^{-1}). Povprečni KON pridelki so bili v skladu s povprečnimi pridelki pšenice v Sloveniji v preteklih letih, medtem ko pa so EKO pridelki bili razmeroma nizki, če upoštevamo vnos hranil preko hlevskega gnoja. BD in INT sistem sta se odrezala bliže skupnemu povprečju vseh sistemov, kar kaže na bolj uravnotežene pridelke. Razloge za relativno veliko razliko med BD in EKO pridelki lahko iščemo v uporabi komposta namesto hlevskega gnoja in/ali uporabi BD pripravkov, za katere je bilo ugotovljeno, da izboljšujejo rodovitnost tal in dostopnost dušika v kompostu.

Povprečni pridelki zelja so bili na nivoju povprečnih pridelkov v Sloveniji in so se statistično značilno razlikovali med leti, ne pa med pridelovalnimi sistemi. Kljub temu obstajajo opazne razlike med tržnimi pridelki pridelovalnih sistemov, kjer so najvišji pridelki bili zabeleženi na EKO in BD parcelah, nato jima sledijo INT, KON in kontrolne parcele. Zdi se, da se je dostopnost hranil preko organske snovi (OS) v tleh pozitivno odrazila na pridelkih zelja, saj je bilo veliko OS v EKO in BD sistemih dodane preko hlevskega gnoja in komposta.

Pridelki semena oljnih buč se niso značilno razlikovali med sistemi ali leti, bili pa so malo pod povprečjem, ugotovljenim v prejšnjih raziskavah. Opazen pa je bil trend količine pridelka glede na sisteme pridelave, kjer je bil najvišji povprečni pridelek izmerjen v BD

sistemu, nato v INT, kontroli, EKO in KON.

AU dodanih N gnojil se je statistično značilno razlikovala med pridelovalnimi sistemi (pri pšenici in zelju) in leti (vse tri poljščine). Kljub temu pa ni skupnega imenovalca glede tega, kateri pridelovalni sistem je imel boljšo AU, saj je dostopnost N in učinkovitost izrabe odvisna neposredno in posredno od velike množine dejavnikov, kjer je vlaga v tleh, vsebnost OS, temperatura in zračnost tal in zahteve po N s strani poljščin med bolj pomembnimi. Boljšo AU pri pšenici sta imela INT in KON sistem, saj so bile moderne sorte pšenice žlahtnene na dobro izrabo dodanega rastlinam dostopnega N. Kljub temu pa je zanimivo, da se BD sistem ni statistično značilno razlikoval od INT in KON sistema. Pri zelju in oljnih bučah je opazen trend boljše AU pri EKO in BD sistemu v primerjavi s KON, INT in kontrolo.

Na AU dodanih P gnojil niso toliko vplivala leta, kot pa sistemi pridelave in poljščini/zelenjadnica. Tako je značilno najvišjo AU pri pšenici imel INT sistem, ki sta mu sledila KON in BD sistem. EKO in kontrola sta imela najnižje vrednosti. Drugačna slika pa se pokaže pri zelju, kjer je bila značilno najvišja AU dosežena v EKO sistemu, ki mu sledijo BD, INT in KON sistem, s kontrolo na zadnjem mestu. Pri bučah ni bilo statistično značilnih razlik med sistemi, je pa opazen trend, kjer ima najvišjo AU BD sistem; sledijo mu INT, kontrola, KON in EKO.

Tudi AU dodanega K je odvisna od leta pridelave (pšenica in oljne buče) in sistema pridelave (pšenica in zelje), kjer so opazna podobna zaporedja in trendi kot pri AU P.

Statistično značilne razlike med pridelovalnimi sistemi so se pojavile pri količini prisotnih epigeičnih deževnikov, kjer jih je bilo več določenih na EKO in BD parcelah vseh kulturnih rastlin. To je najverjetneje posledica dodanega hlevskega gnoja oziroma komposta, ki predstavlja hrano za to vrsto malih deževnikov. Ta skupina deževnikov je bila tudi najbolj številčna od vseh, zato se razlike med sistemi prenesejo tudi na skupno število prisotnih deževnikov. Razlike med pridelovalnimi sistemi ni bilo za endogeične (srednje velike) deževnike pri nobeni od rastlin. Obstaja pa trend večjega števila anecičnih (velikih) deževnikov v EKO in BD sistemih, z izjemo KON sistema pri pšenici, kjer je bilo prisotnih

relativno veliko število velikih deževnikov z navpičnimi rovi. KON parcele pšenice so bile edine, kjer se žita ni česalo (mehansko zatiralo plevela). Veliki deževniki so zelo občutljivi na motnje v njihovem življenjskem prostoru, do viška njihovega razmnoževanja pa pride spomladi, ko so se žita v vseh sistemih, razen KON, česala. Zato je ta motnja možen razlog za takšen rezultat. Številčno in masno največ deževnikov je bilo prisotnih na parcelah buč, kjer je tudi najmanj motenj življenjskega prostora deževnikov v sezoni.

(ii) Razlike v pridelku pšenice so bile obdelane že poglavju (i), pridelki pira pa so bolj izenačeni in razlike niso tako izrazite kot v primeru pšenice. Značilno najvišji pridelek je v BD in INT sistemih (2.440 in 2.369 kg ha^{-1}), ki jima sledita KON in EKO sistem (2.260 in 2.039 kg ha^{-1}), najnižji pridelek pa je v kontroli (1.807 kg ha^{-1}).

Pri okoljskem odtisu vidimo, da velik delež končnega odtisa v KON in INT sistemih izvira iz uporabe mineralnih gnojil in pesticidov. V EKO in BD sistemu pa najvišji delež končnega odtisa pripada uporabi mehanizacije, večinoma zaradi raztrosa organskih gnojil, dodatnega okopavanja in uporabe BD pripravkov v BD sistemu. Zanimivo pa je dejstvo, da imajo tudi kontrolne parcele dokaj visok končni odtis za pridelavo pšenice in pira, saj za pridelavo na 10.000 m^2 (1 ha) pustimo odtis na 67.216 m^2 za pšenico in 74.053 m^2 za piro.

Končni odtis KON sistema je opazno višji od ostalih sistemov pridelave (8 krat višji od EKO in BD sistema); tudi INT sistem se ne odreže veliko bolje, saj je v povprečju končni odtis 4,5 do 6 krat višji od EKO in BD sistema pridelave.

Pri rezultatih za skupni odtis na pridelano enoto (a_{tot}), SPI in okoljsko učinkovitost pridelave (EEP), pa so vključeni tudi pridelki v posameznem pridelovalnem sistemu. Pridelovalni sistemi so statistično značilno vplivali na vse parametre pri pšenici in piri, kjer so kontrola, EKO in BD sistemi, imeli nižje vrednosti za a_{tot} in SPI ter višje za EEP in se tako odrezali veliko bolje kot KON in INT sistema. Tako je razmerje, kjer je kontrola=1 za a_{tot} in SPI znašalo 6-7:1 med KON:kontrola, EEP pa se ne dvigne nad 0,2:1 pri KON:kontrola, medtem ko doseže razmerje 0,9:1 pri BD:kontrola.

Projecirali smo tudi magnitudo spremembe, če bi vse sedanje njivske površine, namenjene pridelavi pšenice in pira v Sloveniji, preusmerili v EKO in BD kmetijstvo. Nivo pridelka (upoštevajoč relativno nizke pridelke v EKO sistemu v našem poskusu) bi se zmanjšal skoraj za tretjino, okoljski odtis in a_{tot} pa skoraj za dve tretjini. Posledično bi se EEP trikratno zvišala. Rešitve za potencialno nižje pridelke bo v prihodnosti potrebno iskati v izboljšavah tehnike pridelave (obdelava tal, gnojenje, itd), spremembi namembnosti zemljišč (pridelava hrane, spremenjen kolobar, vprašanje energetskih rastlin in pozidave najboljših kmetijskih zemljišč) in spremenjeni samooskrbni politiki. Kljub temu pa so spremembe nujne, saj zaloge fosilnih goriv, na katerih dandanes skoraj izključno temelji industrijsko kmetijstvo, pojenjajo in se bodo predvidoma najkasneje do konca tega stoletja tudi iztrošile.

(iii) V obeh letih je pri senzoričnem ocenjevanju sodelovalo 167 oseb različne izobrazbe in starosti, kjer je bil v letu 2009 višji delež starostne skupine med 20 in 29 leti.

Rezultati za zelje so se statistično značilno razlikovali med sistemi pri vonju in pripravljenosti nakupa, saj so potrošniki preferirali vonj zelja iz kontrole napram KON zelju, kjer so INT, BD in EKO vzorci bili med njima. Največjo pripravljenost za nakup so izkazali za INT zelje, ki mu sledi kontrola, EKO, BD in KON zelje. Zasledili pa smo tudi interakcijo pridelovalnega sistema in let pri zelju iz kontrole (barva) in BD parcel (vsi ocenjeni parametri). Razlike med leti bi bilo možno razložiti s količino pridelka in/ali zaščito rastlin/gnojenjem (več ostankov deteljno-travne mešanice v letu 2008 napram 2009 na kontrolnih parcelah, drugo leto uporabe BD pripravkov v letu 2009) s posledično spremenjeno kemično sestavo. Toda pridelki na BD parcelah so bili v obeh letih stabilni. Razlog za razlike v okusu bi lahko iskali tudi v obliki dodanih hranil v pridelovalnih sistemih.

Ocene so se statistično značilno razlikovale med spoloma in pridelovalnimi sistemi pri vprašanju o pripravljenosti nakupa zelja. Ženske so bile na splošno bolj pripravljene kupiti zelje, kjer je bilo na prvem mestu INT zelje, ki mu je sledilo kontrola, KON, BD in EKO zelje. Moški so izrazili podobno preferenco za EKO, INT in kontrolo, ki sta jim sledila BD in KON vzorca.

Vzorca rdeče pese iz kontrole in BD sistema sta bila ocenjena značilno najvišje pri barvi, okusu in pripravljenosti za nakup. Sledili so jim EKO, INT in KON vzorci. Verjetno je, da razlog za to razliko leži v višji vsebnosti sladkorja in/ali fenolnih spojin, katerih je bilo več v BD vzorcih. Ocene za vonj se niso statistično značilno razlikovale med PS.

Razlike med spoloma so bile opazne pri ocenah barve, kjer so moški barvo ocenili bolj enotno kot ženske. Kljub temu pa je bil viden trend podeljevanja višjih ocen alternativnim pridelovalnim sistemom.

Glede na korelacijsko analizo, najmočnejša korelacija obstaja med okusom in pripravljenostjo za nakup pri obeh, belem zelju ($r=0,871$) in rdeči pesi ($r=0,874$). Okusu sledita vonj in barva.

(iv) Največji delež pri sladkorjih v rdeči pesi ima saharoza; fruktoza in glukoza sta bili najdeni samo v majhnih količinah. Skupna vsebnost sladkorjev se je gibala med $21,03 \text{ g kg}^{-1}$ (KON) in $31,58 \text{ g kg}^{-1}$ (BD), kjer pa ni bilo statistično značilnih razlik med sistemi. Kljub temu pa je opazen trend vsebnosti več sladkorjev v ekoloških sistemih pridelave.

V rdeči pesi so bile tudi identificirane štiri organske kisline – citronska, jabolčna, jantarna in fumarna kislina. Jantarne kisline je bilo največ, medtem ko pa so bile ugotovljene statistično značilne razlike med sistemi pri vsebnosti jabolčne kisline. Značilno največ jabolčne kisline je bilo prisotne v vzorcih iz kontrolnih parcel, ki so jim sledili vzorci iz BD parcel. KON, INT in EKO vzorci so vsebovali značilno manj jabolčne kisline kot vzorci iz kontrole. Izločanje jabolčne kisline skozi korenine aktivira bakterije, živeče v področju okoli korenin in vzpodbuja njihovo interakcijo z rastlinami. Rastlinam »prijazne« bakterije tudi vzpostavljajo odpornost na široki spekter listnih bolezni preko aktivacije obrambnih sistemov rastline.

Skupna vsebnost fenolov v vzorcih rdeče pese je bila med $0,51 \text{ mg g}^{-1}$ FW (fresh weight – sveža masa) GAE (»galic acid equivalents«) in $0,68 \text{ mg g}^{-1}$ FW GAE pri KON in BD PS. Vzorci iz BD in kontrolnih parcel so imeli značilno višjo vsebnost skupnih fenolnih spojin kot vzorci iz KON parcel.

Antioksidativna aktivnost, ki je izražena s Trolox ekvivalenti (TE), je bila med 0,823 $\mu\text{M TE g}^{-1}$ FW v KON in 1,270 $\mu\text{M TE g}^{-1}$ FW v BD vzorcih rdeče pese. Tudi pri antioksidativni aktivnosti so vzorci iz BD in kontrolnih parcel imeli višje vrednosti TE kot vzorci iz KON parcel. Obstaja tudi signifikantna pozitivna linearna korelacija med vsebnostjo skupnih fenolov in antioksidativno aktivnostjo ($r^2=0,6187$), kar sovпада z izsledki raziskav na drugih zelenjadnicah.

Na podlagi raziskav lahko zaključimo sledeče:

- (i) BD pridelovalni sistem se je na nivoju pridelkov odrezal kot povprečen oziroma nadpovprečen, saj so pridelki pšenice, zelja in oljnih buč znašali 99, 113 in 124 odstotkov povprečnega pridelka vseh pridelovalnih sistemov - ustrezno. Tudi AU BD sistema za vsa raziskana hranila je bila v zgornji polovici vseh pridelovalnih sistemov. Populacija in biomasa deževnikov sta bili najvišji in na podobnem nivoju v BD in EKO sistemih.
- (ii) Rezultati kažejo na kritične točke v pridelavi pšenice in pire pri vsakem pridelovalnem sistemu, kjer bi se največja izboljšava rezultatov lahko dosegla z opustitvijo uporabe mineralnih gnojil in pesticidov v industrijskih pridelovalnih sistemih. Kljub temu pa tudi uporaba mehanizacije potrebuje pozornost v bližnji in daljni prihodnosti v vseh pridelovalnih sistemih. Glede na projekcijo bi v Sloveniji bilo možno pridelati dovolj krušnih žit z EKO in BD pridelavo ob predpostavkah, da se bo izboljšala tehnika pridelave, spremenila namembnost zemljišč in samooskrbna politika; hkrati pa bi se okoljski odtis občutno zmanjšal, okoljska učinkovitost pa povečala.
- (iii) Pidelovalni sistem, leto pridelave in spol ocenjevalcev so vplivali na oceno senzorične kakovosti vzorcev zelja in rdeče pese. Tako so bili INT in kontrolni vzorci zelja ocenjeni višje kot EKO, BD in KON vzorci. Pri rdeči pesi je situacija drugačna, saj so bili vzorci iz kontrole in BD sistema

ocenjeni višje v večini parametrov kot vzorci iz KON parcel, z EKO in INT vzorci med njimi. Boljše ocene rdeče pese iz BD in kontrolnega sistema pri ženskah kažejo na enega izmed možnih razlogov, zakaj potrošniki ekološke hrane preferirajo EKO in BD hrano napram KON in INT hrani, čeprav to ni bilo potrjeno za zelje.

- (iv) Lahko tudi potrdimo, da obstajajo razlike med pridelovalnimi sistemi pri kakovosti rdeče pese (čeprav včasih obstaja samo trend), saj so bile signifikantno najvišje vrednosti jabolčne kisline, skupnih fenolov in antioksidativne aktivnosti, izmerjene v vzorcih iz kontrole, ki jim sledijo BD, INT in EKO vzorci, nato KON vzorci z najnižjimi izmerjenimi vrednostmi. Pomembno je tudi dejstvo, da so včasih razlike znotraj alternativnih načinov pridelave v enakem obsegu kot med alternativnimi in KON sistemi pridelave. Zato je potrebno vsak pridelovalni sistem primerjati zase in iz tega vidika je tudi težko sprejeti kategorične zaključke glede kakovosti posameznih zelenjadnic.

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Appendix 1: Bibliography of the candidate for years 2003-2011

ARTICLES AND OTHER COMPONENT PARTS

1.01 Original scientific article

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1.25 Other articles or component parts

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MONOGRAPHS AND OTHER COMPLETED WORKS

2.11 Undergraduate thesis

53. TURINEK, Matjaž. Ekološko pridelan ščir (*Amaranthus cruentus* L.) kot dodatek kruhu: diplomsko delo, (Diplomska dela študentov Fakultete za kmetijstvo Univerze v Mariboru, Univerzitetne diplomske naloge). Maribor: [M. Turinek], 2007. VII, 30 f., [7] f., ilustr. [COBISS.SI-ID 2517548]

PERFORMED WORKS (EVENTS)

3.14 Invited lecture at foreign university

54. TURINEK, Matjaž. Bio-dynamische Praxis und Forschungsarbeit- Einsichten eines Lernenden : [vabljeno predavanje v okviru Ringvorlesung WS 2010 BOKU, Wien, 29. 10. 2010]. Wien, 2010. [COBISS.SI-ID 3042860]

3.15 Unpublished conference contribution

55. TURINEK, Matjaž, ZAVODNIK, Franc. Povezovanje med univerzo in organizacijami s področja biodinamike : [prispevek na 13. Alpe Jadran Biosimpoziju z naslovom "Raziskovanje in prenos znanja v ekološkem kmetijstvu", Fakulteta za kmetijstvo in biosistemske vede Univerze v Mariboru, Hoče, 27.-29. 1. 2010]. Hoče, 2010. [COBISS.SI-ID 2938924]

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3.25 Other performed works

57. BAVEC, Martina, REPIČ, Polonca, TURINEK, Matjaž. Ekološka prehrana : [sodelovanje na okrogli mizi Ekološka prehrana, v organizaciji študentskega sveta Fakultete za naravoslovje in matematiko UM, v Mariboru, 10.12.2007]. Maribor, 2007. [COBISS.SI-ID 2599468]
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Curriculum Vitae (short version)

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Date and place of birth: 18.5.1981 in Maribor
Nationality: Slovene

Education:

2007 – 2011	III. Level PhD study of Agronomy at the Faculty of Agriculture and Life Sciences, University of Maribor
2001 – 2007	BSc in Agriculture at the Faculty of Agriculture, University of Maribor
2004 – 2005	Erasmus Exchange – first semester at UWA, Aberystwyth, Wales; second semester at KVL in Copenhagen, Denmark, majoring in Organic agriculture
2000 – 2001	Faculty of Economics and Business, University of Maribor
1996 – 2000	“Prva Gimnazija” high school in Maribor
1988 – 1996	Elementary school in Jarenina

Work Experience:

2007 – Present	Young researcher at Chair of organic agriculture, field crops, vegetables and ornamental plants, Faculty of Agriculture and Life Sciences, University of Maribor
2007	3 month internship at the Research institute for biodynamic agriculture (IBDF) in Bad Vilbel, Germany
2006 – 2007	President of the International Association of students in Agricultural and Related Sciences (IAAS)

Izjava doktorskega kandidata

Podpisani-a Matjaž Turinek, vpisna številka 51052130

izjavljam,

da je doktorska disertacija z naslovom “Comparability of the biodynamic production
system regarding agronomic, environmental and
quality parameters”

- rezultat lastnega raziskovalnega dela,
- da so rezultati korektno navedeni in
- da nisem kršil-a avtorskih pravic in intelektualne lastnine drugih.

Podpis doktorskega kandidata:
