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# ENERGY USE OF DIFFERENT FARMING SYSTEMS IN LONG-TERM TRIAL

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## Abstract

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This study evaluate the effects of different types of agricultural systems and their managements on energy balance over 45-year period (1970–2015). Agricultural systems were (i) spring barley and (ii) winter wheat monocultures with different types of organic supply (straw incorporation, straw incorporation + green manuring, green manuring and control without organic supply) and (iii) Norfolk four-course system. Averaged across each half of study period, total energy inputs ranged between 10.2 GJ $ha^{-1}$ $year^{-1}$ for barley in Norfolk to 22.9 GJ $ha^{-1}$ $year^{-1}$ for wheat in monoculture with green manuring. The results indicate increase of indirect inputs in case of wheat and barley in Norfolk. The only system where the indirect input energy became lower was barley monoculture. Total energy outputs ranged between 198 GJ $ha^{-1}$ $year^{-1}$ for wheat in Norfolk to 88 GJ $ha^{-1}$ $year^{-1}$ for barley in monoculture. Norfolk system had higher output/input ratio than monocultures during whole study period. In almost all systems the effectiveness of energy use decreased during study period when comparing two halves. Yields of cereals throughout all systems were negatively dependent on energy input.

Keywords: energy balance, agricultural system, Norfolk, wheat, Barley, output/input ratio

## INTRODUCTION

The consumption of energy in agriculture is not new theme and is recurring with energy crises (Pimentel *et al.*, 1973). When forecasting agriculturally driven global environmental change, there is too certain and too dark side of the last green revolution (Tilman *et al.*, 2001). Solutions handling the cultivated planet exist - halting agricultural expansion and reducing the environmental impacts of agriculture (Foley *et al.*, 2011). However, it gets more complicated, when for example calling for more food production - to feed the growing population. Scudellari (2015) proposed solid counter arguments. Conforti *et al.* (1997) warrant that, for the production of the same amount of food, a consistent increase in demographic density implies both a larger consumption of fossil energy input and a larger environmental impact.

Definitely, to reduce energy inputs by employing such alternatives as rotations and green manures to reduce the high energy demand of chemical fertilizers and pesticides is obligatory. Steinborn *et al.* (2000) evaluate sustainability of agro-ecosystems on the overproduction of entropy and assumed that differences are due to a varying, but in many cases an excessive, use of fertilisers. When reducing artificial energy input, sustainability was improved. Nevertheless, he stated that all the examined crop fields were far from reaching a sustainable state from a thermodynamic point of view. Energy use is related to many aspects and can be considered differently. Economic net return is higher for the conservation farming system, but when the subsidies from EU are considered, the net return is higher in the organic farming (Sartori *et al.* 2005).

In case of energy balance, it is assumed that crop rotations with legumes and reduced tillage improve energy efficiency (Rathke *et al.* 2007). Adopting diversified crop rotations, together with minimum and zero tillage management practices, will enhance non-renewable energy use efficiency of annual grain production (Zentner *et al.*, 2004).

The aim of this study was to evaluate the effects of different types of agricultural systems and their managements on energy balance over 45-year period (1970–2015). These production systems were compared under the same site conditions and using the same methods for calculating the energy balance values. Agricultural systems were (i) spring barley and (ii) winter wheat monocultures with different types of organic supply (straw incorporation, straw incorporation + green manuring, green manuring and control without organic supply) and (iii) Norfolk four-course system.

## MATERIALS AND METHODS

### Study site

A long-term field experiment were established in the 70s (in 1970 spring barley monoculture, in 1972 winter wheat monoculture and in 1970 Norfolk four-course system). The experiments, located in Moravia close to Kromeriz (Czech Republic, 49°17'N, 17°21'E, 235 m a.s.l.), were originally aimed to study possible levels of crop planting intensification, and after how to mitigate caused negative effects. In the first half of study period (1970–1992) and the second half of study period (1993–2015) average annual rainfall was 557 mm and 591 mm, respectively. For the same time periods average temperature was 8.9 °C and 9.8 °C, respectively. Soil properties were: a luvi-haplic chernozem; clay content 40–47 %; silt 45–49 %; sand 10–20 %.

### Experimental design

The plot size (0.55 ha) of spring barley (*Hordeum vulgare* L.) and winter wheat monoculture (*Triticum aestivum* L.) was split to four subplots (35 × 50 m) with different types of organic supply; straw incorporation (letter A), straw incorporation + green manuring: mustard (*Sinapis alba* L.) (B), green manuring (mustard) (C) and control (D) without organic supply. Mineral fertilizer rates were per year on average: 110 kg N ha$^{-1}$; 40 kg $P_2O_5$ ha$^{-1}$; 80 kg $K_2O$ ha$^{-1}$ for spring barley and 170 kg N ha$^{-1}$; 35 kg $P_2O_5$ ha$^{-1}$; 90 kg $K_2O$ ha$^{-1}$ for winter wheat. The plot of Norfolk four-course system was divided to four rotated subplots (each with an area of 1150 m$^2$); red clover (*Trifolium pratense* L.) (A), winter wheat (B), beetroot (*Beta vulgaris* L. *ssp. esculenta var. crassa*) (C) and spring barley (D). Mineral fertilizer rates per year were: 35 kg $P_2O_5$ ha$^{-1}$; 110 kg $K_2O$ ha$^{-1}$ for red clover, beetroot, spring barley and 100 kg N ha$^{-1}$; 35 kg $P_2O_5$ ha$^{-1}$; 120 kg $K_2O$ ha$^{-1}$ for winter wheat. In addition, for beetroot, dairy cattle slurry rates were: 50 t ha$^{-1}$ year$^{-1}$ and contained on average 4.5 kg N t$^{-1}$, 2.5 kg $P_2O_5$ t$^{-1}$ and 5.5 kg $K_2O$ t$^{-1}$ fresh weight. All plots were treated conventionally with ploughing (to 22 cm depth). Beetroot was treated additionally with mechanical weeding. The rates of mineral fertilizers were dependent on the level in the soil and on type of organic supply. The other agronomic practices were same for all systems.

### Energy balance

System boundaries, fluxes and energetic parameters were determined as reported in by Hulsbergen *et al.* (2001). It is commonly acknowledged that energy coefficients vary in the literature. However, before mentioned work serves in this study as a standard. Energy variables (input, output, ratio etc.) are there defined. From the same source energy coefficients for different input and output values, and fuel consumption, for all field operations as well for energy equivalents for the production means (mineral fertilizers, pesticides. seeds etc.) were adopted.

### Statistical analysis

Data corresponding to two periods (1970–1992) and (1993–2015) were analyzed. One-way ANOVA followed by post-hoc comparison using Tukey HSD test were applied to the all studied variables to identify significant differences amongst systems and crops. Linear regression was used to evaluate the relationship between yields and input energy. All analyzes were performed using the STATISTICA 10 software (StatSoft, Tulsa, USA).

## RESULTS

The difference among years in yields were the result of variation in the weather conditions. All interactions of year with treatments (systems) were significant. To ease the comprehension of the results, the year-to-year data were not shown. Rather, the whole study period was divided to two halves. In Norfolk only results for cereals are displayed for better comparison with yields in monocultures. The means for this rotation system were computed including values for red clover and beet.

### Energy inputs

Averaged across each half of study period, total energy inputs ranged between 10.2 GJ ha$^{-1}$ year$^{-1}$ for barley in Norfolk to 22.9 GJ ha$^{-1}$ year$^{-1}$ for wheat in monoculture with green manuring (Table I). The relative change between two halves of study period was positively highest in case of wheat in Norfolk and negatively highest for barley in monoculture without organic supply (Table III). Direct energy use ranged from 17 % of the total energy inputs in the wheat monoculture system to 41 % in the Norfolk as a system. The relative change of direct energy use was positively highest in barley monocultures. In case of indirect energy, the fertilizers made up the highest contribution (from 30 % for cereals in Norfolk to 61 % in wheat monoculture). The relative change in fertilizes energy amount was highest in Norfolk. Pesticides contributed by one third to indirect inputs in Norfolk and made up about 10 % in monocultures (Table II). The numbers of pesticide operations were higher in monocultures and were doubled for the second half of study period in barley monoculture (Table III).

### Energy outputs and energy efficiency

Averaged across each half of study period, total energy outputs ranged between 198 GJ $ha^{-1}$ $year^{-1}$ for wheat in Norfolk to 88 GJ $ha^{-1}$ $year^{-1}$ for barley in monoculture. The relative change between two halves of study period was significantly and negatively highest for barley in monoculture without organic supply (Table III). Net energy ranged between 184 GJ $ha^{-1}$ $year^{-1}$ for wheat in Norfolk to 69.9 GJ $ha^{-1}$ $year^{-1}$ for wheat in monoculture (Table I). The relative change between two halves of study period was significantly and negatively highest for barley in monoculture without organic supply (Table III). Output/input ratio ranged between 17.40 for wheat in Norfolk to 4.26 for wheat in monoculture (Table I). The relative change between two halves of study period was significantly and negatively highest for wheat in Norfolk (Table III). Averaged yields ranged between 7.70 $10^3$ kg $ha^{-1}$ $year^{-1}$ for wheat in Norfolk to 5.11 $10^3$ kg $ha^{-1}$ $year^{-1}$ for wheat in monoculture (Table I). The relative change between two halves of study period was significantly and negatively highest for barley in monoculture without organic supply (Table III). In Norfolk the yields of cereals increased 5.5 % for barley and 7.7 % for wheat when comparing two halves of study period. Yields across all systems and study period were significantly and negatively dependent on energy input in case of wheat ($R = -0.286$; $P = < 0.001$) but not significant in case of barley ($R = -0.094$; $P = 0.155$).

## DISCUSSION

We do not calculate human labour as it is usual, when concerning developed agriculture. Nawn *et al.* (2016) pointed out, that in the literature on sustainability of agriculture, both laborers and workers are conspicuously absent and found negative surplus to be near-universal in developing country. In study of Quilty *et al.* (2014) manual labour accounted for less than 3 % of the total input and is argued that future production systems will require more mechanisation.

Deike *et al.* (2008) found the largest shares of energy input in integrated farming treatments were diesel fuel and mineral fertilizers. On the other hand, in organic farming treatment, most energy was needed only for diesel fuel. Increased use of inputs $ha^{-1}$ in production is accompanied by a larger increase in the output levels, but nearly all the input energy comes from non-renewable sources of energy (Tabar, *et al.* 2010). In our case, increase of indirect inputs is in accordance with pesticide use. However, pesticides are in many cases made with less energy consumed and are applied in smaller doses e.g. sulfonylureas versus phenoxy herbicides. The increase of indirect inputs in case of wheat and barley in Norfolk is partly caused by raised level of applied nitrogen fertilisers. These levels stabilised around the end in first half of the study period. Hülsbergen *et al.*, (2002) found that at optimum N fertilization, the net energy output increased in the order winter barley-winter wheat-sugar beets. However, in his study there was no clear-cut time trend in the rate of N application required to maximize yield. In our study, the only system where the indirect input energy became lower was barley monoculture. However, this was partly done by changing type of fertiliser, not by rating down the levels. Ammonium sulphate is harmful to soil conditions, it causes acidification. It was replaced after 25 years of use by ammonium nitrate which is less energy demanding (Hulsbergen *et al.*, 2001).

Norfolk system had higher output/input ratio than monocultures during whole study period. Both monocultures are heavily dependent on energy coming from manufactured fertilizes. Norfolk rotation system is organized as to compensate the nutrition loss by using manure that comes from stock. Beetroot in Norfolk has a particular feature in terms of energy use. Today, beet cultivation is energetically more productive and efficient than the cultivation of many other arable crops in Middle Europe (Reineke *et al.*, 2013). However, when considering real energy gain a much lower energy output/input ratio and net energy is expected, given the greater energy inputs required in the transformation process (Koga *et al.*, 2008). In another study, the energy output/input ratio was doubled for sugar beet in comparison to wheat (Kuesters *et al.*, 1999). In our study, energy balance of monoculture variants C and D (green manuring and control) were skewed because the straw is harvested as a byproduct. Monocultures are commonly considered as not balanced in terms of energy. Moreno *et al.* (2011) conclude that cereal monocultures, regardless of management, are an energetically unfavourable. Crop rotations increase energy efficiency.

In our study, almost in all systems effectiveness of energy use decreased during study period when comparing two halves. This can be attributed to increased energy input in case of Norfolk and wheat monoculture or to lowering yields in case of barley monoculture. Yields of wheat monoculture does not shown such a trend. In case of Norfolk the yields of cereals increased. It was stated by Uhlin (1999) that potential of conventional agriculture to bind solar energy creates a much larger effect on energy flows than savings on inputs. He argue, that high input agriculture requires much less land per unit of output and spare land can be used for energy crops and schemes for increased biodiversity. Our results cannot provide evidence for his conclusions.

I: *Effects of management systems on energy variables during study divided to two periods.*

| | | Norfolk four-course system | | | Spring barley monoculture | | | | Winter wheat monoculture | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spring barley | Winter wheat | Norfolk Mean | A | B | C | D | A | B | C | D |
| **Total Energy input (GJ ha$^{-1}$ year$^{-1}$)** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 10.2 a | - | - | 17.5 b | 18.6 c | 18.8 c | 16.4 d | - | - | - | - |
| | (1993-2015) | 11.0 a | - | - | 16.5 b | 17.7 b | 17.9 b | 13.6 c | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 10.9 a | - | - | - | - | - | 20.4 b | 22.5 c | 22.5 c | 19.7 b |
| | (1993-2015) | - | 14.8 a | - | - | - | - | - | 21.4 b | 22.8 b | 22.9 b | 21.6 b |
| **Total** | (1970-1992) | - | - | 11.3 a | 17.5 bc | 18.6 bd | 18.8 b | 16.4 c | 20.4 d | 22.5 e | 22.5 e | 19.7 d |
| | (1993-2015) | - | - | 12.2 bd | 16.5 c | 17.7 c | 17.9 c | 13.6 bd | 21.4 a | 22.8 a | 22.9 a | 21.6 a |
| **Energy output (GJ ha$^{-1}$ year$^{-1}$)** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 150 a | - | - | 94.1 b | 97.6 bc | 151 a | 139 ac | - | - | - | - |
| | (1993-2015) | 159 a | - | - | 88.0 bd | 91.1 bc | 130 ac | 115 cd | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 188 a | - | - | - | - | - | 93.8 b | 94.5 b | 163 c | 154 c |
| | (1993-2015) | - | 198 a | - | - | - | - | - | 91.3 b | 97.3 b | 169 c | 159 c |
| **Total** | (1970-1992) | - | - | 154 b | 94.1 a | 97.6 a | 151 b | 139 b | 93.8 a | 94.5 a | 163 b | 154 b |
| | (1993-2015) | - | - | 153 b | 88.0 a | 91.1 a | 130 bc | 115 cd | 91.3 a | 97.3 ad | 169 b | 159 b |
| **Net energy (GJ ha$^{-1}$ year$^{-1}$)** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 141 a | - | - | 77.4 b | 78.7 b | 132 a | 123 a | - | - | - | - |
| | (1993-2015) | 148 a | - | - | 71.3 b | 73.8 b | 113 a | 101 a | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 177 a | - | - | - | - | - | 73.0 c | 72.5 c | 140 b | 135 b |
| | (1993-2015) | - | 184 a | - | - | - | - | - | 69.9 c | 74.8 c | 146 b | 138 b |
| **Total** | (1970-1992) | - | - | 143 a | 77.4 b | 78.7 b | 132 a | 123 a | 73.0 b | 72.5 b | 140 a | 135 a |
| | (1993-2015) | - | - | 141 a | 71.3 b | 73.8 b | 113 a | 101 a | 69.9 b | 74.8 b | 146 a | 138 a |
| **Output/ input ratio** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 15.0 a | - | - | 5.44 c | 5.23 c | 7.97 b | 8.71 b | - | - | - | - |
| | (1993-2015) | 14.6 a | - | - | 5.40 c | 5.19 c | 7.51 b | 8.42 b | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 17.4 a | - | - | - | - | - | 4.70 b | 4.26 b | 7.42 c | 7.91 c |
| | (1993-2015) | - | 14.5 a | - | - | - | - | - | 4.51 b | 4.45 b | 7.63 c | 7.74 c |
| **Total** | (1970-1992) | - | - | 16.1 a | 5.44 c | 5.23 c | 7.97 b | 8.71 b | 4.70 c | 4.26 c | 7.42 b | 7.91 b |
| | (1993-2015) | - | - | 14.6 a | 5.40 dc | 5.19 d | 7.51 bc | 8.42 b | 4.51 d | 4.45 d | 7.63 b | 7.74 b |
| **Yield ($10^3$ kg ha$^{-1}$ year$^{-1}$)** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 6.71 | - | - | 6.34 | 6.57 | 6.38 | 6.14 | - | - | - | - |
| | (1993-2015) | 7.08 b | - | - | 5.93 ab | 6.13 ab | 5.69 ab | 5.11 a | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 7.15 | - | - | - | - | - | 6.30 | 6.35 | 6.27 | 6.07 |
| | (1993-2015) | - | 7.70 b | - | - | - | - | - | 6.14 a | 6.54 ab | 6.50 a | 6.22 a |
| **Total** | (1970-1992) | - | - | 12.51 a | 6.34 b | 6.57 b | 6.38 b | 6.14 b | 6.30 b | 6.35 b | 6.27 b | 6.07 b |
| | (1993-2015) | - | - | 15.90 a | 5.93 b | 6.13 b | 5.69 b | 5.11 b | 6.14 b | 6.54 b | 6.50 b | 6.22 b |

Monoculture of spring barley and winter wheat are with different type of organic supply; straw incorporation (letter A), straw incorporation + green manuring (B), green manuring (C) and control (D) without organic supply. Means in the same row followed by the same letter do not differ at $P < 0.05$.

II: *Effects of management systems on energy input variables during study divided to two periods.*

| | | Norfolk four-course system | | | Spring barley monoculture | | | | Winter wheat monoculture | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | **Spring barley** | **Winter wheat** | **Norfolk Mean** | **A** | **B** | **C** | **D** | **A** | **B** | **C** | **D** |
| **Energy input (GJ ha$^{-1}$ year$^{-1}$)** | | | | | | | | | | | | |
| **Direct input** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 2.85 (28) c | - | - | 3.17 (18) a | 3.48 (19) ab | 3.69 (20) b | 3.33 (20) a | - | - | - | - |
| | (1993-2015) | 2.92 (27) c | - | - | 3.75 (23) b | 4.28 (24) a | 4.28 (24) a | 3.73 (27) b | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 3.26 (30) a | - | - | - | - | - | 3.93 (19) b | 4.26 (19) c | 4.29 (19) c | 3.66 (19) b |
| | (1993-2015) | - | 2.76 (19) c | - | - | - | - | - | 3.59 (17) b | 4.12 (18) a | 4.16 (18) a | 3.69 (17) b |
| **Total** | (1970-1992) | - | - | 4.68 (41) e | 3.17 (18) a | 3.48 (19) ab | 3.69 (20) bc | 3.33 (20) a | 3.93 (19) c | 4.26 (19) d | 4.29 (19) d | 3.66 (19) bc |
| | (1993-2015) | - | - | 4.53 (37) a | 3.75 (23) b | 4.28 (24) a | 4.28 (24) a | 3.73 (27) b | 3.59 (17) b | 4.12 (18) a | 4.16 (18) a | 3.69 (17) b |
| **Indirect input** | | | | | | | | | | | | |
| **Pesticides** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 1.93 (26) b | - | - | 1.72 (12) ab | 1.96 (13) b | 1.96 (13) b | 1.55 (12) a | - | - | - | - |
| | (1993-2015) | 1.79 (22) ac | - | - | 1.83 (14) a | 1.77 (13) ac | 1.51 (11) c | 1.01 (10) b | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 1.28 (17) a | - | - | - | - | - | 1.74 (11) b | 2.08 (12) b | 1.99 (11) b | 1.86 (12) b |
| | (1993-2015) | - | 2.16 (18) a | - | - | - | - | - | 1.99 (11) b | 1.97 (11) b | 1.84 (10) b | 1.97 (11) b |
| **Total** | (1970-1992) | - | - | 1.01 (14) a | 1.72 (12) bc | 1.96 (13) b | 1.96 (13) b | 1.55 (12) c | 1.74 (11) bc | 2.08 (12) b | 1.99 (11) b | 1.86 (12) b |
| | (1993-2015) | - | - | 1.24 (15) ac | 1.83 (14) b | 1.77 (13) bd | 1.51 (11) cd | 1.01 (10) a | 1.99 (11) b | 1.97 (11) b | 1.84 (10) b | 1.97 (11) b |
| **Seeds** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 1.81 (25) | - | - | 1.96 (14) | 1.99 (13) | 1.89 (13) | 1.91 (15) | - | - | - | - |
| | (1993-2015) | 1.77 (22) | - | - | 1.87 (15) | 1.84 (14) | 1.91 (14) | 1.86 (19) | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 2.11 (28) | - | - | - | - | - | 2.43 (15) | 2.48 (14) | 2.49 (14) | 2.43 (15) |
| | (1993-2015) | - | 2.26 (19) | - | - | - | - | - | 2.47 (14) | 2.45 (13) | 2.63 (14) | 2.63 (15) |
| **Total** | (1970-1992) | - | - | 1.68 (23) a | 1.96 (14) a | 1.99 (13) a | 1.89 (13) a | 1.91 (15) a | 2.43 (15) b | 2.48 (14) b | 2.49 (14) b | 2.43 (15) b |
| | (1993-2015) | - | - | 1.67 (20) a | 1.87 (15) a | 1.84 (14) a | 1.91 (14) a | 1.86 (19) a | 2.47 (14) b | 2.45 (13) b | 2.63 (14) b | 2.63 (15) b |
| **Machinery** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 1.41 (19) a | - | - | 2.61 (18) b | 2.48 (16) b | 2.69 (18) b | 2.63 (20) b | - | - | - | - |
| | (1993-2015) | 1.39 (17) a | - | - | 2.77 (22) b | 2.36 (18) b | 2.45 (18) b | 2.21 (22) b | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 1.90 (25) a | - | - | - | - | - | 2.52 (15) b | 2.91 (16) b | 2.92 (16) b | 2.51 (16) b |
| | (1993-2015) | - | 3.27 (27) a | - | - | - | - | - | 2.84 (16) b | 2.89 (15) b | 2.95 (16) b | 2.74 (15) b |

| | | Norfolk four-course system | | | Spring barley monoculture | | | | Winter wheat monoculture | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | Spring barley | Winter wheat | Norfolk Mean | A | B | C | D | A | B | C | D |
| **Total** | (1970-1992) | - | - | 1.77 (24) a | 2.61 (18) b | 2.48 (16) b | 2.69 (18) b | 2.63 (20) b | 2.52 (15) b | 2.91 (16) b | 2.92 (16) b | 2.51 (16) b |
| | (1993-2015) | - | - | 2.15 (25) a | 2.77 (22) bc | 2.36 (18) a | 2.45 (18) ac | 2.21 (22) a | 2.84 (16) b | 2.89 (15) b | 2.95 (16) b | 2.74 (15) b |
| **Fertilizer** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 2.20 (30) a | - | - | 8.01 (56) b | 8.67 (57) b | 8.56 (57) b | 6.91 (53) c | - | - | - | - |
| | (1993-2015) | 3.12 (39) a | - | - | 6.23 (49) cb | 7.43 (55) c | 7.73 (57) c | 4.78 (48) ab | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 2.35 (31) a | - | - | - | - | - | 9.71 (59) b | 10.53 (59) b | 10.80 (59) b | 9.21 (58) b |
| | (1993-2015) | - | 4.31 (36) a | - | - | - | - | - | 10.5 (59) b | 11.39 (61) b | 11.28 (60) b | 10.56 (59) b |
| **Total** | (1970-1992) | - | - | 2.95 (40) a | 8.01 (56) c | 8.67 (57) cd | 8.56 (57) cd | 6.91 (53) b | 9.71 (59) e | 10.53 (59) e | 10.83 (59) e | 9.20 (58) de |
| | (1993-2015) | - | - | 3.47 (41) a | 6.23 (49) bd | 7.43 (55) b | 7.73 (57) b | 4.78 (48) ad | 10.5 (59) c | 11.39 (61) c | 11.28 (60) c | 10.56 (59) c |
| **Total Indirect input** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 7.35 (72) a | - | - | 14.3 (82) bc | 15.1 (81) b | 15.1 (80) b | 13.0 (80) c | - | - | - | - |
| | (1993-2015) | 8.07 (73) b | - | - | 12.7 (77) ac | 13.4 (76) a | 13.6 (76) a | 9.86 (73) bc | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 7.64 (70) b | - | - | - | - | - | 16.4 (81) a | 18.2 (81) c | 18.2 (81) c | 16.0 (81) a |
| | (1993-2015) | - | 12.0 (81) a | - | - | - | - | - | 17.8 (83) b | 18.7 (82) b | 18.7 (82) b | 17.9 (83) b |
| **Total** | (1970-1992) | - | - | 6.63 (59) b | 14.3 (82) cd | 15.1 (81) ac | 15.1 (80) ac | 13.0 (80) d | 16.4 (81) a | 18.2 (81) e | 18.2 (81) e | 16.0 (81) a |
| | (1993-2015) | - | - | 7.67 (63) c | 12.7 (77) ad | 13.4 (76) a | 13.6 (76) a | 9.86 (73) cd | 17.8 (83) b | 18.7 (82) b | 18.7 (82) b | 17.9 (83) b |
| **N. of pesticide operations** | | | | | | | | | | | | |
| **Spring barley** | (1970-1992) | 1.3 a | - | - | 1.9 b | 1.9 b | 1.9 b | 1.9 b | - | - | - | - |
| | (1993-2015) | 3.0 b | - | - | 4.6 a | 4.6 a | 4.6 a | 4.6 a | - | - | - | - |
| **Winter wheat** | (1970-1992) | - | 1.6 b | - | - | - | - | - | 3.3 a | 3.1 a | 3.1 a | 3.1 a |
| | (1993-2015) | - | 3.2 b | - | - | - | - | - | 4.8 a | 4.7 a | 4.7 a | 4.7 a |
| **Total** | (1970-1992) | - | - | 1.1 a | 1.9 b | 1.9 b | 1.9 b | 1.9 b | 3.3 c | 3.1 c | 3.1 c | 3.1 c |
| | (1993-2015) | - | - | 2.1 a | 4.6 b | 4.6 b | 4.6 b | 4.6 b | 4.8 b | 4.7 b | 4.7 b | 4.7 b |

Monoculture of spring barley and winter wheat are with different type of organic supply; straw incorporation (letter A), straw incorporation + green manuring (B), green manuring (C) and control (D) without organic supply. Means in the same row followed by the same letter do not differ at $P < 0.05$. The contribution of field operation on indirect input and direct input on total input or is shown in percent in parentheses.

III: *Change of energy attributes and yields*

| Energy variable | Norfolk-course system | | | Spring barley monoculture | | | | Winter wheat monoculture | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Spring barley | Winter wheat | Mean | A | B | C | D | A | B | C | D |
| **Total Energy input** | 7.8 | **35.8** | **8.0** | -5.7 | -4.8 | **-4.8** | **-17.1** | 4.9 | 1.3 | 1.8 | 9.6 |
| **Energy outpout** | 5.9 | 5.6 | -0.6 | -6.5 | -6.7 | **-13.5** | **-17.7** | -2.7 | 3.0 | 3.6 | 3.1 |
| **Net energy** | 5.7 | 3.8 | -1.2 | -6.7 | -7.2 | -14.7 | **-17.9** | -2.7 | 3.5 | 3.9 | 2.2 |
| **Output/input ratio** | -2.7 | **-16.7** | **-9.3** | -0.7 | -0.8 | -5.8 | -3.3 | -4.3 | 4.5 | 2.8 | -2.1 |
| **Yield** | 5.5 | 7.7 | | -6.5 | -6.7 | -10.8 | **-16.8** | -2.5 | 3.0 | 3.7 | 2.5 |
| **Indirect input** | | | | | | | | | | | |
| **Pesticides** | -7.3 | **68.8** | **22.5** | 6.4 | -9.7 | **-23.0** | **-34.8** | 14.4 | -5.3 | -7.5 | 5.9 |
| **Seeds** | -2.2 | 7.1 | -0.3 | -4.6 | -7.5 | 1.1 | -2.6 | 1.6 | -1.2 | 5.6 | 8.2 |
| **Machinery** | -1.4 | **72.1** | **21.5** | 6.1 | -4.8 | -8.9 | **-16.0** | 12.7 | -0.7 | 1.0 | 9.2 |
| **Fertilizer** | **41.8** | **83.4** | **17.8** | **-22.2** | -14.3 | -9.7 | **-30.8** | 8.1 | 8.2 | 4.4 | 14.8 |
| **Total Indirect input** | **9.8** | **57.1** | **15.7** | **-11.2** | -11.3 | -9.9 | **-24.2** | 8.5 | 2.7 | 2.7 | 12 |
| **Direct input** | 2.5 | -15.3 | -3.2 | **18.3** | **23.0** | **16.0** | 12.0 | -8.7 | -3.3 | -3.0 | 0.8 |
| **N. of pesticide operations** | **131** | **100** | 91 | **142** | **142** | **142** | **142** | **45** | **52** | **52** | **52** |

Relative change is shown in percent where two halves (1970-1992) and (1993-2015) of the study period were compared. Monoculture of spring barley and winter wheat are with different type of organic supply; straw incorporation (letter A), straw incorporation + green manuring (B), green manuring (C) and control (D) without organic supply. Bold figures indicate the difference was significant at P = 0.05.

## CONCLUSION

This study evaluate the effects of different types of agricultural systems and their managements. The results of energy balance in this 45-year study indicate the importance of long term trial. The trends in energy use are not always easily anticipated and the differences between systems are not clear cut. It is assumed, that when increasing energy inputs higher energy gains are assured. In our study, there are results supporting the opposite. The results show, that crop rotations are better than monocultures also from energy efficiency point of view. Recorded increase in use of pesticides, fertilizers and diesel evoke threatened sustainability. Future research should be carried on more agricultural systems and locations to obtain more robust information about the variation between managements and the orientation of long-term trends.

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