AGRICULTURAL AND FOOD SCIENCE

Agricultural and Food Science (2024) 33: 212–222

https://doi.org/10.23986/afsci.146579

Yield variation and yield potential of organic arable crops in Finland derived from statistical data

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This study aims to expand and diversify the analysis of crop yields in organic production by utilising the long-term statistical data reported by farmers. We examined the variation of the harvested yields of organic arable crops (season's ad hoc harvest) on Finnish organic farms and determined the yield potential for different organic crops and in comparison, with conventional counterparts. When comparing median yields per ha, organic yields were on average 65% of conventional yields. The mean yield difference significantly differed between plant species. Among the analysed crops, faba bean performed best, gaining on average 84% of conventional yields, while organic cereals attained an average of 54–68% of conventional yields. The ratio of organic and conventional median yields was compared between geographical regions, and significant regional differences were found. The performance of organic cereals remained stable over the years, but the relative performance of the organic grain legumes, pea and faba bean, depended more on growing conditions. An average yield gap between the best-performing and median farms was 38% for organic farms and 28% for conventional farms. This indicates that Finnish organic farms have greater potential to improve the yield level than conventional farms.

Key words: yield gap, organic farming, conventional farming

Introduction

In organic production, yield levels are generally 20–30% lower than in conventional production (de Ponti et al. 2012, Mayer et al. 2015, Ponisio et al. 2015). The lower yield level of organic production than conventional production is also a key criticism of organic production and its environmental sustainability (Mondelaers et al. 2009, Tuomisto et al. 2012, Clark and Tilman 2017). The gained yields in organic production systems can vary remarkably, depending on crop type and geographical region (Wilbois and Schmidt 2019), and presumably also among farms, and estimates of the average performance have therefore only limited practical use (Seufert and Ramankutty 2017).

Nitrogen deficiency has been cited as the dominant factor explaining lower yields in organic farming systems (Bagley et al. 2007, Barbieri et al. 2021) but many other common factors affect crop performance, such as weed pressure, the occurrence of pests and diseases, poor soil health, and field drainage conditions. When organic yields are compared with conventional yields, the results also depend on the input intensity of conventional production (Seufert et al. 2012). The optimal use of synthetic fertilisers secure yields, enabling the achievement of high yield levels in conventional systems, while in organic farming systems, the management of crop nutrients relies more on soil processes such as the mineralisation of soil organic matter (Brock et al. 2011). Ponisio et al. (2015) showed that yield gaps were significantly lower when nitrogen input was similar between organic and conventional treatments. It has also been reported that the yield gap between organic and conventional farming systems can decline over a longer period due to the greater spatial stability of soil properties and processes in organic farming systems (Schrama et al. 2018). It should also be remembered that farm-scale comparisons between organic and conventional yields are not only affected by agronomical factors but by farmers' business choices and motivation to target the maximum yield.

Boreal agriculture is characterised by a harsh winter and a short and intense growing season. The increase of soil temperature affects the rate of mineralisation of soil organic matter, and it can be challenging to get nutrient availability to coincide with the nutrient demand of the crop in organic farming systems, especially in the spring. It is therefore obvious that yield gaps between organic and conventional farming systems may be even greater in cool northern climate conditions than in temperate climate conditions.

Received 19 June 2024 / Accepted 17 October 2024

The Scientific Agricultural Society of Finland

The study's first aim was to examine the variation in the yields of organic arable crops on Finnish organic farms and to determine the yield potential of different organic crops. Yield potential is essential for an individual farmer to benchmark their own yield against the best-performing farms but also offers us a better understanding of the overall potential of organic farming systems to produce cash crops compared with conventional systems. The second aim was to compare organic yields with conventional ones in different regions and to analyse underlying factors that explained the variation in organic crop yields in Finland.

Material and methods

Statistical data and the sample frame

The Crop Production Statistics contain information about the production of the most significant crops in Finland (Luke 2024). The statistics describe the production quantities of crops in total and by area. In addition to total production, the statistics are divided into organic and conventional production.

Since 2013, the statistical population of the statistics has included agricultural and horticultural enterprises with a financial value of more than EUR 2,000. The financial value is determined using the Standard Output (SO) method (Eurostat 2024). Standard output SO is the average income in euros per hectare received for agricultural products, or euros per livestock by farm prices. The prices used in the calculating Standard Output are five-year averages. SO does not take subsidies into account because subsidies are separate from production in EU agricultural policy. Subsidies per product therefore cannot be calculated.

The production line is determined in accordance with the agricultural or horticultural enterprise's most economically significant product. These data are calculated using the SO method. If more than two thirds of a farm's total output come from a single product, the farm is included in the production line category corresponding with this product. If this is not the case, the farm's production line is mixed production.

The sample for the Crop Production Statistics was drawn as a stratified sample from both conventional and organic farms. The sample frame was constructed with three variables: geographical location (16 areas); production line (6–7 classes); and economic value (5–6 classes). The sample was allocated using the Neymann allocation. The allocation variable was the economic value of the farm. After initial stratification, small strata with only a few farms were combined. The stratification was updated and checked after data collection using the most recent register data (post-stratification). The sample size was about 5 600 conventional farms and about 700 organic farms. The share of organic farms in the sample corresponded to the relative share of organic farms in Finland.

Data were collected with an online survey and telephone interviews, and the season's harvested yield levels (kg per ha) given were estimated by the farmers themselves. Farmers reported the yields of pre-wilted silage and the dry matter percentage of the pre-wilted silage. Silage yield was converted accordingly to 100% dry matter yield. Yields of other crops are presented dried to the moisture of 14 %. The data collection application was implemented by the Finnish Food Authority. The same operator took care of the storage of data in the database. The total response rate was about 90%.

The results were estimated with SAS software, using the weighting coefficients below.

The weighting coefficient at stratum level was determined by stratum weighting using equation

$$h=Nh/(nh-mh),$$

where Nh = the number of farms in stratum h,

nh = the number of sample farms in stratum h, and

mh = the number of non-respondent sample farms (= non-response) in stratum h.

Variances were estimated using the CLAN macro in the SAS software developed by Statistics Sweden. Average yields of the organic and the conventional main crops by region and the whole country are published in the statistics database maintained by Luke (Luke 2024).

Principles for the evaluation of yield parameters

Yield potential can be measured in the best possible growing conditions using modelling tools (Aramburu-Merlos et al. 2024). If it is intended to define yield potential locally, a lot of modelling is needed to consider the weather conditions occurring in a certain region each year. An alternative approach for estimating the local yield potential is to observe the maximum yield achieved among farmers in a region of interest (Palosuo et al. 2015). A large sample size is needed for the estimation. The current study applied this approach, with minor modifications. The potential was calculated only for those regions where at least 20 farmers had cultivated a certain crop in that year. The potential was calculated separately for organic and conventional cultivation, and the same limit was applied to both. Mistakes in the information given by individual farmers were possible, as the harvest was not always necessarily measured but could be reported by farmers. Because a few large incorrectly reported yields may be included in the data reported by farmers, the 90th percentile of the distribution of yield was used instead of the maximum (i.e. 90% of the yields in the distribution are equal to or lower than the potential). This indicator is more robust than the maximum for single erroneous yield values, and its magnitude does not depend on whether there were 20 or 200 farmers in the sample. The latter reason is important when comparing organic and conventional farming because there are significantly fewer organic than conventional farms in the sample.

The yield gap was calculated by subtracting the achieved average yield from the yield potential (Lobell et al. 2009). The yield gap was calculated for every crop species as absolute and relative gaps. If the yield exceeded the potential, the gap was set to zero. The yield gap distribution was studied using descriptive statistics (mean, standard deviation, graphical methods). The actual statistical analyses were performed on the yield gaps of the median farm. The data contain eight years (2014–2021) and 14 areas of Centres for Economic Development, Transport and the Environment, ELY Centres. As not all crops were cultivated in all areas, and the requirement of 20 farmers was not always met, the maximum number of area-by-year combinations in the study was 128.

In addition, yield comparisons were made at the regional level according to the climate conditions during the study period. This was conducted by dividing annually collected regional yield data into three categories: low, normal, and high yield. The categorisation was made by comparing the yields of different crops from 14 regions and eight years (a total of 112 combinations) and arranging the combinations by order of magnitude based on the average yields of all crops. In the categorisation, it was considered that not all crops appeared in all combinations (i.e. two-way ANOVA with missing values if the yields of a crop did not exist in the data). Both organic and conventional farming were considered, and the same categories were used for all crops and both farming types. Each category represents an average yield level during years when the average yield was low, normal, or high.

Statistical methods

Variations in yield gap and yield as kilos per ha and relative to the long-term average yield were modelled using a variance component model. By identifying potential sources of variation in yield and yield gap, a variance component model (Solomon 2005) was fitted to the data, which includes all areas and years. The farm's background information was added to the data (e.g. farming system, farm size, farm type). In practice, a random effect model was fitted to obtain estimates of the contributions different factors made to the overall variability of the yield data as expressed by their variance. Analysis was performed using SAS/MIXED software.

The years and regions were divided based on the yield level into three equal sized categories: low, average, and high yield levels. All crops were considered in the classification. Two-way analysis of variance was used to test whether the difference between organic and conventional is the same at different categories (farm type x growing category interaction). Interaction was tested separately for each crop in order to identify crops where the performance of organic crops varies annually depending on the yield level made possible by weather conditions.

The rest of the analysis was based on a one-way ANOVA model or a mixed model, in which the variable of interest (e.g. crop, farming system) was used as a fixed effect, and the random effects were year, area, and their interaction. If there was more than one factor of interest, their interaction effect was also included in the model. Analysis was performed using SAS/MIXED software.

Results

Yield comparisons between organic and conventional farms

When comparing median yields, organic yields per ha in a given season were on average 65% of conventional yields. The mean yield difference significantly differed between plant species ($p < 0.001$). Among the analysed crops, faba bean performed best, gaining on average 84% of conventional yields, while autumn-sown rye gained only 54% of conventional yields (Fig. 1). When species were grouped into crop groups such as grain legumes, cereals, oil crops, and silage, organic oil crops gained the lowest yield (57%), and grain legumes the highest (77%), compared with conventional crops (Table 1). Organic grain legumes performed significantly better than leys, cereals, and oil crops. Leys performed better than cereals as a group. There was also variation among cereals. Organic winter wheat attained on average 68%, barley 65%, oat 59%, spring wheat 58%, and rye 54% of conventional yields.

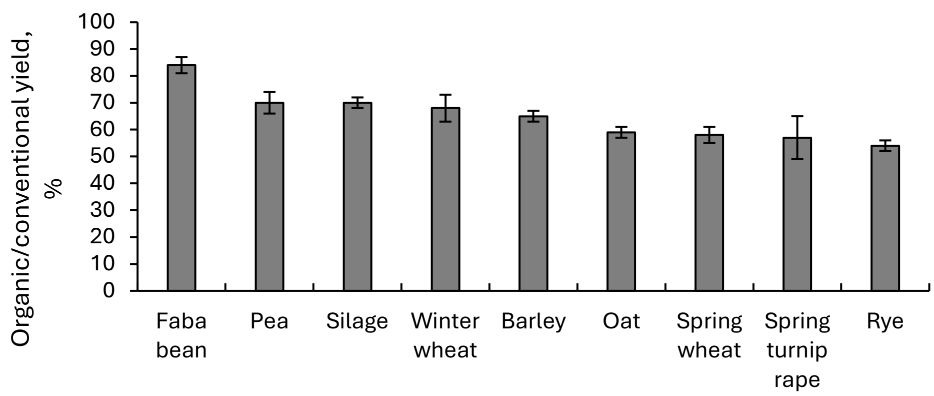

Fig. 1. Relative organic yield (%) of median farms for nine crops compared with conventional counterparts (=100 %). Vertical lines express the standard error of the mean.

Table 1. Relative (± SE, standard error of the mean) organic yields (ORG) compared with conventional (CON) yields of the median farms for four crop groups. Pairwise comparisons of groups are shown next to the ratio. Ratios with the same letter do not differ statistically significantly.

Crop group	Relative yield ORG vs. CON, %
Grain legumes	77 ± 3 a
Silage	70 ± 2 b
Cereals	61 ± 2 c
Oil crops	57 ± 8 bc

The ratio of organic and conventional median yields was compared between geographical regions in Finland, and significant differences between regions were found ($p < 0.01$). Organic yields were highest at 73% of the conventional ones in Central Finland and lowest at 58% of the conventional ones in the Satakunta and Häme regions. The ratios did not differ significantly between crops, except for organic rye, which performed relatively better in comparison to conventional rye in the regions of Eastern Finland than in the regions of Southern and Western Finland (Fig. 2).

The organic yields of all crops compared with conventional ones were almost significantly affected by circumstances ($p = 0.06$). Organic farms gained an average of 66% of yields gained on conventional farms in favourable growing conditions facilitating a generally high yield performance. Organic farms gained an average of 61% of yields gained on conventional farms in more challenging growing conditions. The performance of organic cereals remained stable across years ($p = 0.94$), but the relative performance of the organic grain legumes, pea and faba bean, depended on growing conditions ($p < 0.001$). The organic yield of grain legumes was an average of 65% of the yield gained on conventional farms during low yield years but significantly higher at 79% during years with more favourable growing conditions.

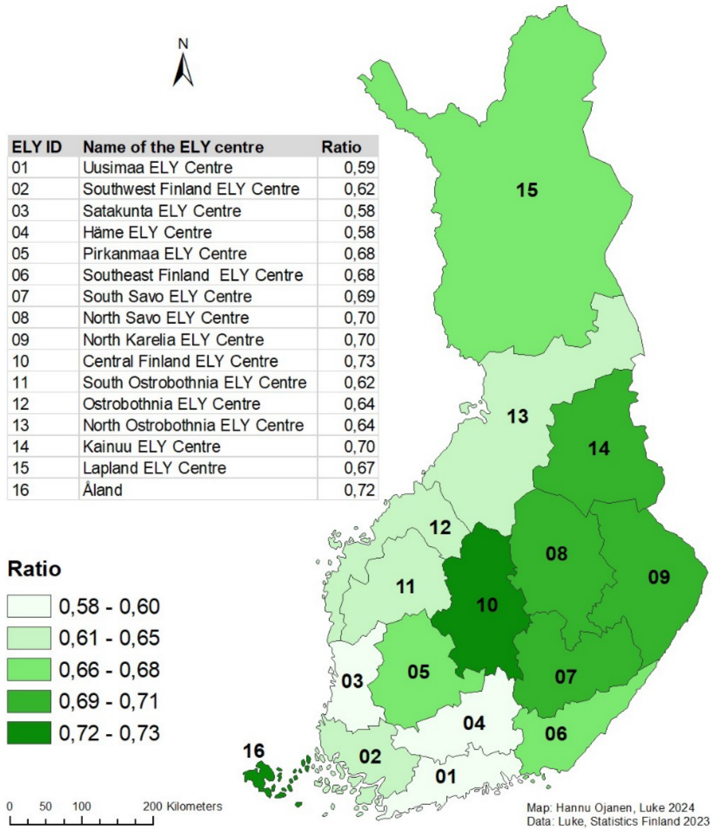

Fig. 2. The ratios of organic median crop yields to conventional median crop yields in different ELY Centre regions in Finland.

Yield potential and yield gap for different crops

An average yield gap between the best-performing farms and median farms was 38% for organic farms and 28% for conventional farms. When the yield gaps between different organic and conventional crops were considered, it was found that the organic yield gap was greater for all other crops except silage compared with conventional ones (Table 2).

Table 2. Yield potentials, median yields, and yield gaps of different organic and conventional crops. Yields are given in kg ha^{-1}. For cereals and grain legumes, the yield is given as dried to the moisture of 14 % and silage yield on 100% dry matter.

	Conventional			Organic		
Crop	Yield potential	Median yield	Yield gap	Yield potential	Median yield	Yield gap
Silage	8807	4693	0.47	6222	3235	0.48
Faba bean	3081	2026	0.34	2253	1352	0.40
Winter wheat	6125	4410	0.28	4175	2296	0.45
Spring wheat	4845	3587	0.26	3004	1832	0.39
Oat	4644	3340	0.28	3108	1927	0.38
Barley	4644	3338	0.28	3474	2253	0.35
Pea	3191	2489	0.22	2979	2026	0.32

Yield potential was lower on organic farms than on conventional farms for all the studied crops (Table 2). When organic yield potentials are compared with the median yields of conventional crops, it can be observed that the yields of organic faba bean and pea are higher, and organic winter wheat, oat, and barley were only slightly lower, than conventional yields.

Yield variation between years and among farm types

The yield variation between years was greater on conventional than on organic farms when the variation was measured in kilograms produced per hectare (Table 3). Measured as a percentage of the average crop yield, the difference disappeared, but the variation on organic farms was still smaller in some cases. For example, relative annual variation for barley, rye, winter wheat, and faba bean was smaller on organic farms.

The organic yield varied among farms. When the effects of crop, region, and year were taken into account, at least two significant factors explained the remaining variation. First, farm size is one explanatory factor. Depending on crop species, farm size (<25 ha, 25–50 ha, 50–100 ha, >100 ha) explains 1.5–12.8% of the variation. Silage had the lowest, and winter wheat the highest, explained variation. Farm size remarkably affects yield variation, especially for organic wheat, barley, rye, and spring turnip rape yields. Larger farms gained higher average yields (e.g. the difference between farms of <25 ha and >100 ha is estimated to be more than 700 kg ha^{-1} for winter wheat). Another explanatory factor was the type of farm. The average yield was higher on organic livestock farms than on organic farms concentrating on plant production. The lowest variation explained by farm type was for pea (0.2%); the highest was for silage (10.8%).

Table 3. Standard deviation for yield variation by year and farm size category. The variation has been presented separately for conventional (CON) and organic (ORG) farm types in kg ha^{-1} and relative to the long-term average crop yield (%).

	Year				Farm size category			
Crop	kg ha^{-1}		%		kg ha^{-1}		%	
	CON	ORG	CON	ORG	CON	ORG	CON	ORG
Winter wheat	930	242	23.9	11.2	343	305	8.8	14.1
Rye	646	199	20.6	11.6	445	203	14.2	11.8
Spring wheat	602	333	17.6	17.4	252	253	7.4	13.2
Faba bean	494	327	25.7	21.5	197	172	10.2	11.3
Oat	478	307	14.8	15.8	273	209	8.4	10.8
Barley	472	253	14.7	12.2	251	251	7.8	12.1
Silage	376	263	7.7	7.7	934	665	19.1	19.6
Pea	220	163	8.7	8.8	235	173	9.3	9.4
Spring turnip rape	28	16	2.3	2.2	93	88	7.7	12.5

Discussion

The utilized long-term statistical data reported by farmers includes several years, crops, regions and, at the same time, a large selection of different farms and farmers. The farmers are also not the same every year. The farmer made a yield estimate, the accuracy of which we do not know. The large number of estimates gives the opportunity to evaluate possible bias. Since the observed differences between organic and conventional farming are systematic across years with different weather conditions, and the relative differences in crops and regions also vary with the same systematics from year to year, the results can be considered unbiased, and the large number of farms guarantees that the accuracy of the results is more than sufficient for the purposes of this study. The collected statistical data offered us a unique opportunity to analyse yields in organic production in an unbiased way.

Season's harvested cereal yields per ha on organic farms were an average of 61% of those obtained on conventional farms, varying from the lowest value of 54% for rye to the highest value of 68% for autumn wheat. Previous studies have reported that organic cereal yields vary from 74 to 78% of those gained in conventional systems, but significantly lower values of 60 to 64% have been reported for wheat (de Ponti et al. 2012, Seufert et al. 2012, Mayer et al. 2015, Ponisio et al. 2015). Field trials conducted in the Nordic and Baltic countries have reported a 34–44% decrease in cereal yields in organic farming (Kirchmann 2007, Ingver et al. 2008), which is consistent with our results. The productivity of cereals in organic cropping systems is typically limited by scarce nitrogen availability, especially in legume-based cropping systems (Döring and Neuhoff 2021). On livestock farms, nutrient management can obviously be more successfully controlled for cereals through manure availability and the pre-crop value of mixed legume and grass silage swards compared with solely plant production farms. This may explain the higher average yields on livestock farms than on farms concentrating on plant production, as seen in this study. Another explanation for the much better performance of cereals in conventional systems may be the use of modern cultivars adapted to utilise synthetic inputs and the lack of varieties bred for their performance in organic farming systems. Weed invasion has been a continuing challenge in organic cereal production, which has been observed in the surveys on weed flora in spring cereals in Finland (Hyvönen et al. 2003, Salonen et al. 2001, 2013, 2023). A substantially increased total biomass of weeds was associated with organic cropping due to the lack of direct weed control methods and inadequate crop competition (Salonen et al. 2013). In the latest survey (Salonen et al. 2023), the average density of weeds was 384 plants m^{-2} in organic fields and 147 plants m^{-2} in herbicide-sprayed conventional fields. The average air-dry biomass of weeds was 678 kg ha^{-1} and 151 kg ha^{-1}, respectively. Higher weed pressure in organic cereal fields is probably one of the factors reducing the yields obtained in organic production in relation to conventional production.

On Finnish organic farms, the grass cultivation acreage has a bigger share of the total cultivation than on conventional farms (Iivonen et al. 2023), suggesting that a higher proportion of the cereal crops are nurse crops for silage crops. This was observed in the weed survey, as 41% of the cereal fields were sown as nurse crops for grass stands (Salonen et al. 2001). When cereals are cultivated as a nurse crop to establish a grass stand, it is recommended to use cultivars resistant to early lodging and 25% lower sowing density than with pure cereal cultivation to avoid the risk of lodging and provide good establishment conditions for the grass stand (Puurunen and Virkajärvi 2010). The hectare yield of cereals is therefore anticipated to be somewhat lower in nurse cereal crops than in pure cereal crops. This may slightly reduce the hectare yields of cereals in organic production in relation to conventional production. In the 5-year study of Känkänen and Eriksson (2007) the decrease in barley yield by undersown timothy and red clover was, however, only 0–5% although the studied highest sowing rates were 1600 and 600 seeds m^{-2} for timothy and red clover, respectively.

Grain legumes was the group of arable crops in organic farms that reached closest to yields obtained in conventional farming, which confirms previous studies (Seufert et al. 2012, Ponisio et al. 2015). Legumes are mandatory in the crop rotations of organic farms in Finland, and organic farmers have therefore also developed skills in cultivating grain legumes, which are also generally challenging to cultivate on conventional farms, with a large interannual variability in yield seen in this study as well. Faba bean is sensitive to drought, and variation in rainfall has therefore been reported to play a major role in grain yield stability (Link et al. 1999). Lower grain yields can also result in decreased growing days, as drought triggers the maturation of faba bean (Skovbjerg et al. 2020). Current commercial faba bean cultivars also consist of a large variation in grain yield and yield stability (Skovbjerg et al. 2020). Organic grain legumes produced less (65%) in relation to conventional production in low yielding conditions than in more favourable conditions (79%). Starting nitrogen is typically applied in the spring on conventional farms, and it is possible that in seasons that are cool early, organic fields suffer more often from low biological nitrogen fixation and slow nitrogen mobilisation from organic sources.

In contrast with previous studies (Seufert et al. 2012, Ponisio et al. 2015), organic oilseed crops did not perform better than organic cereals in Finland. This is probably because oilseed crops mainly consist of spring turnip rape which in Finland, frequently suffers from losses to pest insects (Hakala et al. 2011). In addition to the challenges in plant protection, other unidentified factors associated with the cultivation of spring turnip rape have been reflected in the weak development of seed crop yields in Finland (Peltonen-Sainio et al. 2007).

Organic grassland–ruminant systems typically enable a high input of N to the soil and yields of grass-clover forage crops are therefore often similar in organic and conventional systems (Eltun et al. 2002, Kirchmann et al. 2007). However, this was not seen in this study, as organic silage yields were only 70% of the silage yields in conventional production. However, in interpreting the silage yields in yield statistics-based data, it is good to be aware of some error possibilities in the silage production data. Organic farmers may have used part of the silage acreage for grazing or for green manuring, and this would decrease silage hectare yields. On organic plant production farms, the utilisation of silage acreage for green manuring may be quite high. In silage production, the farm type explained a higher proportion (10.8%) of yield variation than in the other species. The yield gap was very high in silage production in both conventional and organic production. This suggests that farm-connected reasons may have a bigger impact on silage production than on other species. Livestock farmers tend to secure an adequate silage yield even for low yielding years with a large acreage, and in good years, maximum hectare yields can be achieved when feed demand has already been met. In a previous study (Koikkalainen and Lötjönen 2014), the ratio of organic silage yield to conventional yield was 0.82, and fertiliser input was very low in organic production. The absence of starting nitrogen application in the spring prior to the onset of the nitrogen fixing process in cool soil and omitting the third cut to provide good overwintering possibilities for red clover may somewhat reduce organic silage production yields based on mixed swards.

Although organic yields are typically lower than conventional yields, yield differences are highly contextual, and our analysis shows that there is an unexploited potential to improve yield levels on Finnish organic farms. The potential for improvement is even bigger on organic farms than on conventional ones for several crops, which indicates that when the best organic management practices are used in favourable conditions, yields are closer to conventional yields, as previously documented in earlier studies (Riesinger 2010, Seufert et al. 2012). An explanatory factor for the achievement of higher yields is farm size. Bigger farms gain a higher yield, probably for several reasons such as a more professional attitude, capabilities of investing in soil health and crop rotation, the use of modern cultivars, and perhaps the use of manure on livestock farms. The study of Peltonen-Sainio and Jauhiainen (2010) showed that modern cultivars were generally superior to their predecessors in nitrogen use efficiency, which can be expected to be even more important in organic than in conventional production due to challenges in meeting crops' nitrogen demand. Larger farms have better opportunities to plan crop rotation (Peltonen-Sainio et al. 2017, Peltonen-Sainio and Jauhiainen 2019), which is the key to successful nutrient management and preventive plant protection on organic farms. The ongoing increase in farm size and the reduction in the number of farms could further support the transition to more diverse crop sequencing (Peltonen-Sainio and Jauhiainen 2019). Lötjönen et al. (2004) suggested that the collaboration between organic production farms or renting more fields (Koikkalainen and Lötjönen 2014) to facilitate specialisation in production enabled the maintenance of an adequate diversity in the whole system. Our study also indicated that livestock farms could gain higher yields than farms concentrating on plant production. Livestock farms can obviously offer better nitrogen availability for cereals through manure management and the pre-crop value of mixed legume grass silage swards than plant production farms.

In favourable growing conditions, organic farms gained an average of 66% of the yields of conventional farms, while in more challenging growing conditions, when yield levels remained generally low, organic farms gained 61% of the yields of conventional farms. This finding is inconsistent with previous studies, which have presented better relative performance in organic yields in more challenging environmental conditions (Wilbois and Schmidt 2019). Challenges affecting yield levels and opportunities to harvest crops may differ on boreal organic farms operating during much shorter and cooler growing seasons than on organic farms in temperate and tropical climate zones.

Our results describe the situation in real conditions, where farmers' targets for cultivation and decisions are influenced by several, even controversial, factors. Farmers do not always attempt to achieve high yields but will often seek to maximise profitability. While organic yields are lower, organic farms have been documented to be more profitable for several concurrent reasons such as higher subsidies and market prices and lower input costs (Röös et al. 2018, Luke 2022). Kuosmanen et al. (2021), however, revealed a significant performance gap between organic and conventional farms in favour of conventional farms. The material used in the study was from 2010–2017, and a positive trend was revealed in organic production at the end of the study period. Kujala et al. (2022) have described the socioeconomic factors affecting Finnish farmers' motivation to switch to organic production. According to their study, the importance of subsidies is one of the key factors that is associated with regional differences in organic farming in Finland. Cultivation area-based subsidies play a bigger role in farmers' decision making in Eastern Finland than in more market-driven areas in Southwest Finland.

In this study's regional comparisons, the relative performance of organic yields was generally better in Eastern than in Southwest Finland. The highest organic shares of field area exist in Eastern Finland, where grain yields are lower than the average for Finnish farms. Pietola and Oude Lansink (2001) found that agro-ecological conditions directly affected farmers' abilities to benefit from organic agriculture in Finland, and organic farms are therefore more likely to be in areas with poorer soil quality and a lower average yield potential. Malek et al. (2019) found similar patterns in several other countries.

This study's constraint is that yield analyses were not conducted throughout the crop rotation cycle from the same parcel. In addition, the yield statistics consider only the yields of the harvested acreage, and sown and unharvested areas are excluded. According to Connor (2022) smaller yields per crop area in organic farming are further reduced at farm level due to land required in cultivation of green manure crops and pastures. An examination of the yields of all the sown parcels throughout the crop rotation would offer us a more precise understanding of the yield potentials of organic farms in Finland.

Conclusions

Our study shows that it would be possible to achieve significantly higher yields on Finnish organic farms. The yield potential assessment gives us a better understanding of the yield levels the best organic farms are achieving. It also provides farmers with comparative information about potentially achievable yields in certain years in regions with similar weather conditions. There are differences in the performance of different organic crops, but regions also differ, which reminds us that the targets set for improving organic production must be considered in context. It should be kept in mind that organic production is inherently prone to local variations in conditions and therefore improvements in yields closer to yield potential might be challenging to achieve. Next, a closer examination should be made of the farming practices of farms achieving yield potentials, and the transfer of expertise should be promoted among the wider group of farmers targeting greater yields. Our study also shows that an increase in farm size can contribute to the goal of increasing yields and highlights the importance of the integration of animal husbandry and plant production in nutrient management.

Although this study compared organic yields with conventional ones and shows that it is possible to increase organic yields, this does not mean it is desirable to achieve similar yields in organic production to those in conventional production. Yield levels of organic production should be increased, taking environmental sustainability into account.

Acknowledgements

This study was funded by the Ministry of Agriculture and Forestry from the Catch the Carbon Research and Innovation Programme.

References

Aramburu-Merlos, F., van Loon, M.P., van Ittersum, M.K. & Grassini, P. 2024. High-resolution global maps of yield potential with local relevance for targeted crop production improvement. Nature Food 5: 667–672. https://doi.org/10.1038/s43016-024-01029-3

Badgley, C., Moghtader, J., Quintero, E., Zakem, E., Jahi Chappell, M., Avilés-Vázquez, K., Samulon, A. & Perfecto, I. 2007. Organic agriculture and the global food supply. Renewable Agriculture and Food System 22: 86–108. https://doi.org/10.1017/S1742170507001640

Barbieri, P., Pellerin, S., Seufert, V., Smith, L., Ramankutty, N. & Nesme, T. 2021. Global option space for organic agriculture is delimited by nitrogen availability. Nature Food 2: 363–372. https://doi.org/10.1038/s43016-021-00276-y

Brock, C., Fließbach, A., Oberholzer, H.-R., Schulz, F., Wiesinger, K., Reinicke, F., Koch, W., Pallutt, B., Dittman, B., Zimmer, J., Hülsbergen, K.-J. & Leithold, G. 2011. Relation between soil organic matter and yield levels of nonlegume crops in organic and conventional farming systems. Journal of Plant Nutrition and Soil Science 174: 568–575. https://doi.org/10.1002/jpln.201000272

Clark, M. & Tilman, D. 2017. Comparative analysis of environmental impacts of agricultural production systems, agricultural input efficiency, and food choice. Environmental Research Letters 12: 064016. https://doi.org/10.1088/1748-9326/aa6cd5

Connor, D.J. 2022. Relative yield of food and efficiency of land-use in organic agriculture A regional study. Agricultural Systems 199: 103404. https://doi.org/10.1016/j.agsy.2022.103404

de Ponti, T., Rijk, B. & van Ittersum, M.K. 2012. The crop yield gap between organic and conventional agriculture. Agricultural Systems 108: 1–9. https://doi.org/10.1016/j.agsy.2011.12.004

Döring, T.F. & Neuhoff, D. 2021. Upper limits to sustainable organic wheat yields. Scientific Reports 11:12729. https://doi.org/10.1038/s41598-021-91940-7

Eltun, R., Korsæth, A. & Nordheim, O. 2002. A comparison of environmental, soil fertility, yield, and economical effects in six cropping systems based on an 8-year experiment in Norway. Agriculture, Ecosystems and Environment 90: 155–168. https://doi.org/10.1016/S0167-8809(01)00198-0

Eurostat 2024. Glossary: Standard Output (SO). https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Standard_output_(SO). Cited 31.5.2024.

Hakala, K., Hannukkala, A., Huusela-Veistola, E., Jalli, M. & Peltonen-Sainio, P. 2011. Pests and diseases in a changing climate a major challenge for Finnish crop production. Agricultural and food science 20: 3–14. https://doi.org/10.2137/145960611795163042

Hyvönen, T., Ketoja, E., Salonen, J., Jalli, H. & Tiainen, J. 2003. Weed species diversity and community composition in organic and conventional cropping of spring cereals. Agriculture, Ecosystems and Environment 97: 131–149. https://doi.org/10.1016/S0167-8809(03)00117-8

Iivonen, S., Koikkalainen, K., Miettinen, A. & Autio, S. 2023. Tavoite 5. Luonnonmukaiseen maatalouden piiriin kuuluva maatalousmaa ja agroekologisten käytäntöjen käyttö. In: Kärkkäinen, L. & Koljonen, S. (eds.). Arvio EU:n biodiversiteettistrategian vaikutuksista Suomessa (2. painos). Luonnonvara- ja biotalouden tutkimus 33/2023. Luonnonvarakeskus. Helsinki. p. 148–167. (in Finnish).

Ingver, A., Tamm, I. & Tamm, Ü. 2008. Effect of organic and conventional production on yield and the quality of spring cereals. Latvian Journal of Agronomy, 11, LLU. 61.

Kirchmann, H., Bergström, L., Kätterer, T., Mattsson, L. & Gesslein, S. 2007. Comparison of Long-Term Organic and Conventional Crop-Livestock Systems on a Previously Nutrient-Depleted Soil in Sweden. Agronomy Journal 99: 960–972. https://doi.org/10.2134/agronj2006.0061

Koikkalainen, K. & Lötjönen, T. 2014. Luomunaudanlihantuotannon taloustarkastelut. In: Huuskonen, A. (ed.). Edistystä luomutuotantoon - loppuraportti. MTT Raportti 175. p. 92–108. (in Finnish).

Kujala, S., Hakala, O. & Viitaharju, L. 2022. Factors affecting the regional distribution of organic farming. Journal of Rural Studies 92: 226–236. https://doi.org/10.1016/j.jrurstud.2022.04.001

Kuosmanen, N., Yli-Heikkilä, M. & Väre, M. 2021. Productive performance of organic crop farms in Finland 2010–2017. Organic Agriculture 11: 379–392. https://doi.org/10.1007/s13165-020-00343-x

Känkänen, H. & Eriksson, C. 2007. Effects of undersown crops on soil mineral N and grain yield of spring barley. European Journal of Agronomy 27:25–34. https://doi.org/10.1016/j.eja.2007.01.010

Link, W., Abdelmula, A.A., Kittlitz, E.V., Bruns, S., Riemer, H. & Stelling, D. 1999. Genotypic variation for drought tolerance in *Vicia faba*. Plant Breeding 118: 4774–84. https://doi.org/10.1046/j.1439-0523.1999.00412.x

Lobell, D.B., Cassman, K.G. & Field, C.B. 2009. Crop Yield Gaps: Their Importance, Magnitudes, and Causes. Annual Review of Environment and Resources 34:179–204. https://doi.org/10.1146/annurev.environ.041008.093740

Lötjönen, T., Muuttomaa, E., Koikkalainen, K., Seuri, P. & Kleemola, E. 2004. Laajamittaisen luomutuotannon teknologia - taloudellinen toteuttavuus ja ekologinen kestävyys. Maa- ja elintarviketalous 44. (in Finnish).

Luke 2022. Kannattavuuskerroin (luomu/tavanomainen tuotanto). https://www.luke.fi/fi/tilastot/indikaattorit/agrikaattori-maaseutuohjelman-indikaattorit-20142020/kannattavuuskerroin-luomutavanomainen-tuotanto. Cited 18.6.024. (in Finnish).

Luke 2024. Statistics database. https://statdb.luke.fi/PXWeb/pxweb/fi/LUKE/

Malek, Z., Tieskens, K.F. & Verburg, P.H. 2019. Explaining the global spatial distribution of organic crop producers. Agricultural Systems 176: 102680. https://doi.org/10.1016/j.agsy.2019.102680

Mayer, J., Gunst, L., Mäder, P., Samson, M.F., Carcea, M., Narducci, V., Thomsen, I.K. & Dubois, D. 2015. Productivity, quality and sustainability of winter wheat under long-term conventional and organic management in Switzerland. European Journal of Agronomy 65: 27–39. https://doi.org/10.1016/j.eja.2015.01.002

Mondelaers, K., Aertsens, J. & Van Huylenbroeck, G. 2009. A meta-analysis of the differences in environmental impacts between organic and conventional farming. British Food Journal 111: 1098–1119. https://doi.org/10.1108/00070700910992925

Palosuo, T., Rötter, R.P., Salo, T., Peltonen-Sainio, P., Tao, F. & Lehtonen, H. 2015. Effects of climate and historical adaptation measures on barley yield trends in Finland. Climate Research 65:221–236. https://doi.org/10.3354/cr01317

Peltonen-Sainio, P., Jauhiainen, L. & Hannukkala, A. 2007. Declining rapeseed yields in Finland: how, why and what next? The Journal of Agricultural Science 145: 587–598. https://doi.org/10.1017/S0021859607007381

Peltonen-Sainio, P. & Jauhiainen, L. 2010. Cultivar improvement and environmental variability in yield removed nitrogen of spring cereals and rapeseed in northern growing conditions according to a long-term dataset. Agricultural and Food Science 19: 341–353. https://doi.org/10.2137/145960610794197588

Peltonen-Sainio, P. & Jauhiainen, L. 2019. Unexploited potential to diversify monotonous crop sequencing at high latitudes. Agricultural systems 174: 73–82. https://doi.org/10.1016/j.agsy.2019.04.011

Peltonen-Sainio, P., Jauhiainen, L. & Sorvali, J. 2017. Diversity of high-latitude agricultural landscapes and crop rotations: Increased, decreased or back and forth? Agricultural Systems 154: 25–33. https://doi.org/10.1016/j.agsy.2017.02.011

Pietola, K. & Oude Lansink, A. 2001. Farmer response to policies promoting organic farming technologies in Finland. European Review of Agricultural Economics 28:1–15. https://doi.org/10.1093/erae/28.1.1

Ponisio, L.C., M'Gonigle, L.K., Mace, K.C., Palomino, J., de Valpine, P. & Kremen, C. 2015. Diversification practices reduce organic to conventional yield gap. Proceedings of the Royal Society B: Biological Sciences 282: 20141396. https://doi.org/10.1098/rspb.2014.1396

Puurunen, T. & Virkajärvi, P. 2010. Nurmen perustaminen. In: Peltonen, S., Puurunen, T. & Harmoinen, T. (eds.). Nurmirehujen tuotanto ja käyttö. Tieto tuottamaan 132: 43–48. (in Finnish).

Riesinger, P. 2010. Agronomic challenges for organic crop husbandry. Doctoral Thesis in Agroecology. Department of Agricultural Sciences Publications. University of Helsinki. ISBN 978-952-10-4302-4

Röös, E., Mie, A. & Wivstad, M. 2018. Risks and opportunities of increasing yields in organic farming. A review. Agronomy for Sustainable Development 38: 14. https://doi.org/10.1007/s13593-018-0489-3

Salonen, J., Jalli, H., Muotila, A., Niemi, M., Ojanen, H., Ruuttunen, P. & Hyvönen, T. 2023. Fifth survey on weed flora in spring cereals in Finland. Agricultural and Food Science 32: 51–68. https://doi.org/10.23986/afsci.130009

Salonen, J., Hyvönen, T., Kaseva, J. & Jalli, H. 2013. Impact of changed cropping practices on weed occurrence in spring cereals in Finland - a comparison of surveys in 1997–1999 and 2007–2009. Weed Research 53: 110–120. https://doi.org/10.1111/wre.12004

Salonen, J., Hyvönen, T. & Jalli, H. 2001. Weed flora in organically grown spring cereals in Finland. Agricultural and Food Science in Finland 10: 231–242. https://doi.org/10.23986/afsci.5689

Schrama, M., de Haan, J.J., Kroonen, M., Verstegen, H. & van der Putten, W.H. 2018. Crop yield gap and stability in organic and conventional farming systems. Agriculture, Ecosystems and Environment 256: 123–130. https://doi.org/10.1016/j.agee.2017.12.023

Seufert, V. & Ramankutty, N. 2017. Many shades of gray-The context-dependent performance of organic agriculture. Science advances 3: e1602638. https://doi.org/10.1126/sciadv.1602638

Seufert, V., Ramankutty, N. & Foley, J.A. 2012. Comparing the yields of organic and conventional agriculture. Nature 485: 229–232. https://doi.org/10.1038/nature11069

Skovbjerg, C.K., Knudsen, J.N., Füchtbauer, W., Stougaard, J., Stoddard, F.L., Jansson, L. & Andersen, S.U. 2020. Evaluation of yield, yield stability, and yield-protein relationship in 17 commercial faba bean cultivars. Legume Science 2020:2:e39. https://doi.org/10.1002/leg3.39

Solomon, P.J. 2005. Variance Components. Wiley StatsRef: Statistics Reference Online. https://doi.org/10.1002/0470011815.b2a09056

Tuomisto, H., Hodge, L.D., Riordan, P. & Macdonald, D.W. 2012. Does organic farming reduce environmental impacts? -A meta-analysis of European research. Journal of Environmental Management 112: 309–320. https://doi.org/10.1016/j.jenvman.2012.08.018

Wilbois, K.-P. & Schmidt, J.E. 2019. Reframing the Debate Surrounding the Yield Gap between Organic and Conventional Farming. Agronomy 9: 82. https://doi.org/10.3390/agronomy9020082