Mind the gap – exploring the yield gaps between conventional and organic arable and potato crops

The OK-Net Arable project promotes exchange of knowledge among farmers, farm advisers and scientists with the aim of increasing productivity and quality in organic arable cropping in Europe. ***Janie Caldbeck*** *and* ***Phil Sumption*** *present the findings from some of the project outputs*[1,2] *so far, concerning the yield gaps between conventional and organic crops.*

What does research tell us?

An increasing yield gap between organic and best practice conventional agriculture is becoming evident. Reviews of global literature for temperate and mediterranean climate zones reveal the difference in yield gaps of organic and conventional farms range from 9-25% (see Table 1 below), with 20% identified in the two most comprehensive studies reviewed. The comparative ecological advantages of organic farming systems are considered relevant as long as the yield difference is no bigger than 20%. In this range of approximately 20% less yields in organic farming, N_2O emissions have been found to be equal in organic and conventional systems. However within the context of a growing yield gap, the role of organic farming could be questioned; some research findings have revealed that yields of organic crop rotations shrank to 50% even under good climate and soils conditions, in comparison to yields attained within good integrated farm practices. It is vital that best organic practices are combined with ecological, social and technological innovation in order to address this.

Table 1: Yield gaps calculated by different meta-analyses (all categories and all crops under consideration)

Study	*Category*	*Crop*	*Yield gap*
Lotter 2003	All	All	-10-15%
Seufert et al. 2012	All	All	-25%
Stanhill 1990	All	All	-9%
Ponisio et al. 2014	All	All (global)	-19%
de Ponti et al. 2012	All	All	-20%
Badgley et al. 2007	All	All (developed countries)	-9%

Applying an agroecological approach

The report *The Role of Agroecology in Sustainable Intensification*[3] also provides some valuable insights. Analysis of different farming approaches points towards agroecological approaches being able to maintain or increase productivity, with the exception of organic farming, where yields per hectare may be substantially reduced due to restrictions on the use of agrochemical inputs. However organic system productivity with respect to other inputs including labour, and in terms of resource use (other than land) per unit of food produced, may be similar or better.

Agroecological practices, such as using rotations and polycultures, biological pest control, or legumes to biologically fix nitrogen (N), can be used by farmers across all farming systems. Agroecology emphasises the idea of 'system redesign' rather than 'input substitution' for maximum benefit.

Low yields are perceived to be a disadvantage of the organic approach (although reductions compared with conventional systems reported in different studies have been highly variable). In the UK, organic wheat yields are typically little more than half those of conventional systems. However, this reduced productivity is exacerbated by the need for fertility building crops in the rotation, meaning that organic farmers cannot grow wheat every year. The additional land area required to grow a tonne of wheat may therefore be higher than a simple comparison of relative yields would suggest.

Some research suggests that with good management practices, particular crop types and growing conditions, organic systems can nearly match conventional yields. Studies have also found that multi-cropping (polycultures) and crop rotations when applied only in organic systems could substantially reduce the yield gap.

Why the gap exists

Crop yield is the result of a transformation of natural resources, farmer knowledge and system inputs. All three transformation processes differ between organic and conventional agriculture and the biggest differences are on the input side (see Figure 1).

1. Transformation of natural resources

Both conventional and organic systems rely on a starting point of site-specific natural resources: light availability, the inherent fertility of the soil, and local climatic conditions. However, conventional and organic systems do not necessarily respond identically to the same starting conditions. Higher soil microbial diversity and activity in soil commonly found under organic conditions may

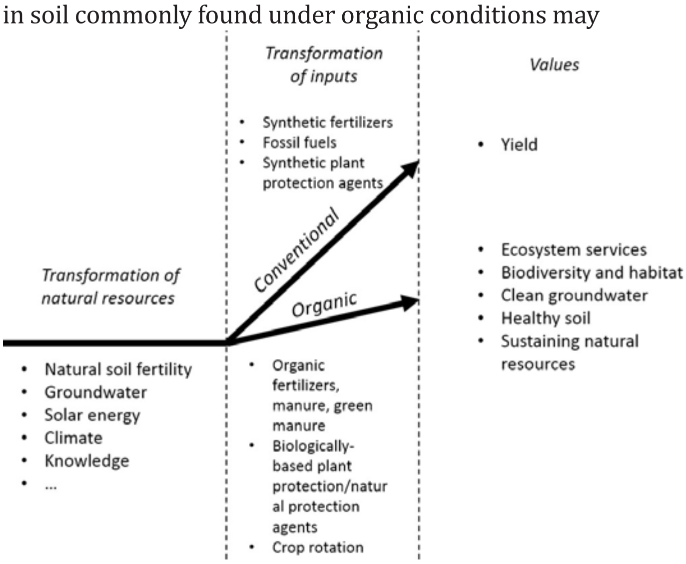

Figure 1: Cropping systems as a process of transformation: a conceptual model (farmer knowledge is mentioned under natural resource for simplicity of the figure only).

increase the bioavailability of nutrients and organic carbon stored in the soil to crops managed under these conditions. Organically managed soil also has advantages in dry conditions, with higher soil organic matter levels increasing soil water capacity. Compared with conventional approaches, organic agriculture provides a more attractive alternative under changing climate conditions; it increases carbon sequestration, has higher energy use efficiency and resilience to climate change, and reduces global warming potential.

2. Farmer knowledge

All farming systems depend largely on farmer knowledge. Organic and conventional farmers both use the best available and appropriate technology and the knowledge related to it. Conventional farmers however have more 'quick fixes' available, while organic farmers rely more on observations of agroecosystems, preventative planning, and traditional knowledge. Knowledge about organic agriculture is less widely available and more time consuming to acquire.

3. System inputs

As can been see in the model illustrated in Figure 1, conventional farmers have the upper hand in transforming inputs into yield. Applying this model to cereals, grain and forage legumes, oilseeds, and tubers, helps to explain why yield gaps reported in meta-analytical studies differ for these crop categories. Differences in inputs account for conventional/organic yield gaps, but each crop category is unique in terms of which inputs are most significant. Gaps are not determined by the average of yield losses imposed by individual factors, but by the factor that has the greatest influence on yield, i.e. nutrient availability for cereals and tubers, weeds and disease for legumes, insect pests for oil crops such as rapeseed.

Table 2: Yield gaps calculated by different meta-analyses (category 'cereals', different crops under consideration)

Study	*Crop*	*Yield gap*
Eltun 1996	Barley, oats, wheat	-30%
Eltun et al. 2002	Barley, oats, wheat	-35%
Gabriel et al. 2013	Cereals	-54%
Poutala et al. 1994	Cereals	-25%
Seufert et al. 2012	Cereals	-26%
Badgley et al. 2007	Cereals (developed countries)	-7%
de Ponti et al. 2012	Cereals (global average)	-21%
Cavigelli et al. 2008	Corn	-24-41%
Larsen et al. 2014	Corn	-50%
Poudel et al. 2002	Corn	NS
Wortman et al. 2012	Corn	-13-33%
Lotter et al. 2003	Corn (legume rotation)	-62%
Lotter et al. 2003	Corn (manure-fertilized)	+37%
Wortman et al. 2012	Sorghum	-16-27%
Cavigelli et al. 2008	Wheat	NS
Ryan et al. 2004	Wheat	-17-84%
Wortman et al. 2012	Wheat	-10-+10%
Arncken et al. 2012	Winter wheat	-42%
Bilsborrow et al. 2013	Winter wheat	-39%
Hildermann et al. 2009	Winter wheat	-38%
Mäder et al. 2002	Winter wheat	-10%
Mäder et al. 2007	Winter wheat	-14%
Mayer et al. 2015	Winter wheat	-36%
Posner et al. 2008	Corn, soybean, wheat	-10%

What does research reveal per crop type?

Cereals

The yield gap for cereals as a whole has been found to be generally lower than for vegetables, but higher than for legumes. As can be seen in Table 2, statistical analysis has revealed yield gaps for cereals fall within a range of 7-26%.

Maize has generally been found to have a smaller yield gap than the overall average for all crop types, whereas barley and wheat have larger yield gaps. It is possible that barley and wheat do not perform well under lower input conditions as they have been bred to thrive in high input conditions. The productivity of maize in organic systems may be explained by the necessity to wait for planting until the soil is warm enough and mineralisation activity is high enough. Weeds can be a major limiting factor, however, organic weed management can be very effective; the yield gap has been found to be as little as 1% in years where mechanical weed cultivation was successful; 26% when it was unsuccessful. Crop rotation can also have significant impact; organic maize grown in rotation with multiple cover crop species can yield over 100% more than organic maize grown in monocultures, attaining yields comparable to the county average for conventional maize.

Research has found nitrogen (N) availability is the primary factor limiting cereal productivity, and differences in N inputs account for the majority of yield gaps. Natural N mineralisation processes often do not correspond with the times of greatest N uptake in wheat, so N availability from natural sources has less impact than inputs that help to form crop yield. Synthetic N fertilisers can be better targeted to crop demand peaks in conventional systems, and cereal yields can be higher in these systems. However, it is possible to increase N availability by using organic best practices. Research shows that supplementing with farmyard manure can raise organic cereal yields in a N-limited system. Use of biogas slurry or green manure and management strategies that better match the timing of N availability to crop requirements can also increase N availability.

Protein content is often considered an important indicator of quality in cereals; it contributes to baking properties and has been the subject of many conventional/organic comparisons. Studies have found 3-23% lower protein content in organic wheat as compared to conventional, with N limitation being the key factor. However, other factors should also be considered e.g. quality rather than quantity of protein gives a better indication of the baking properties of organic wheat, and the practice used by conventional farmers of applying fertiliser late in the year to boost grain protein often leads to it leaching into groundwater and causing nitrate pollution.

Lampkin *et al.*[3] report interesting findings when the productivity of whole farming systems was assessed (and the total production of commodities from a system measured, rather than individual commodities), and applied to data for different farm types taken from the 2009 English Farm Business Survey (FBS). It was revealed that organic specialist cereal, general cropping and mixed farms performed less well compared to non-organic than dairy farms in terms of tonnes of wheat equivalent (tWe) produced per hectare. This may be related to findings that arable farms generally have much higher gross energy outputs per hectare than dairy farms. The results reflect the impact of using some land for fertility-building in organic farming, and emphasise the challenge for farmers of using the fertility-building phase of the rotation effectively. The performance with respect to farm business income per tWe produced and tWe produced per £ spent on inputs was found to be higher than conventional, despite the lower output per hectare. Greenhouse gas emissions were similar between organic and conventional with respect to tWe produced.

Lampkin *et al.*[3] also reflect on the extent to which yield differences can be explained by the N dependency of conventional systems. Research has found that increased N use in conventional production has widened the yield gap to organic. Non-organic UK wheat yields have varied with nitrogen use since the mid-1970s. N can be a major yield-limiting factor in many organic systems. UK organic wheat yields, at 4-5 t/ha, are comparable to conventional yields in the mid-1970s, and much higher than pre-war yield levels when no fertilisers were used. In the US, where conventional wheat is produced less intensively (with average yields about 3t/ha), studies show more similar yields. Within the UK, yield differences for crops such as oats and field beans, where less N is used conventionally, are also lower.

Legumes

Yield gaps are generally much smaller for legumes than for other crop categories. This is due to greater farmer reliance on natural sources of fertility (legumes obtain N primarily through the symbiosis with diazotrophic bacteria), crops requiring negligible inputs, other nutrients not usually being limited, and plant protection agents being seldom used. Lampkin *et al.*[3] highlight that better performance of legumes and perennials could be due to better N utilisation, rather than higher N levels. In many developing countries, resource-poor farmers unable to afford purchased N fertilisers have demonstrated potential to increase yields using organic/agroecological approaches. Grain legumes have been found to have a slightly higher yield gap than forage legumes, but the gap is still much smaller than for other crop categories, and yields can sometimes be higher under organic conditions. Beans have been found to have significantly higher yields under organic conditions. In developed countries, the yield gap for legumes has been found to be higher than cereals (see Table 2 and Table 3). Legume yields were 52% higher under organic conditions when considered globally.

Table 3: Yield gaps calculated by different meta-analyses (category 'legumes', different crops under consideration)

Study	*Crop*	*Yield gap*
Seufert et al. 2012	Legumes	NS
Badgley et al. 2007	Legumes (developed countries)	-18%
de Ponti et al. 2012	Legumes (global average)	-12%
Cavigelli et al. 2008	Soybean	-19%
Wortman et al. 2012	Soybean	-17%
Lotter et al. 2003	Soybean (legume rotation)	+96%
Lotter et al. 2003	Soybean (manure-fertilized)	+52%

Yield gaps can arise when inputs differ significantly. The way in which weeds and diseases are managed can limit organic yields if no biologically-based strategies are used. The largest yield gap calculated for soybeans has been attributed to pest and disease management and phosphorus limitation. The 19% soybean yield gap (see Table 3) was attributed entirely to weeds.

Oil crops

The yield gap between oil crops grown organically and conventionally is often small (see Table 4). Some crops such as oilseed rape can be impossible to grow under organic conditions due to insect pests. Sunflower is a crop for which organic yields levels can often equal conventional levels, contributing to the small yield gaps reported for oilseeds. Ponti et al. (see Table 4) found organic oilseed yields to be 26% lower than conventional due to insect herbivory and there being no effective organic methods of control for pests such as the pollen beetle. Oilseed rape however is unusual as almost all production in Central Europe is conventional. Yields can also be affected by weeds, particularly when crops are at sensitive developmental stages, but differences in plant protection agents have the biggest impact on the yield gap. This suggests that research into organic pest control methods should be prioritised.

Table 4: Yield gaps calculated by different meta-analyses (category 'oil crops')

Study	*Crop*	*Yield gap*
Seufert et al. 2012	Oil crops	NS
Badgley et al. 2007	Oil crops (developed countries)	-1%
de Ponti et al. 2012	Oil crops (global average)	-26%

Tubers

The yield gap for tubers is often greater than for cereals but can be more variable (see Table 5). Of 21 organic/conventional comparisons carried out of organic potato yields in Europe, the yield was found to be only 70% compared to conventional. Organic sugar beet and sweet potato yields however were 105%, raising the tuber average to 74% of conventional. In potatoes, the primary yield-limiting factor is nutrient availability. Pathogens such as P*hytophthora infestans* also have a big impact. Some research has found that 48% of the yield gap in organic potato could be attributed to N limitation, and 25% to disease for which no organic management is possible. Inputs of synthetic fertilisers and plant protection can therefore be primarily attributed to the higher yields found in conventional farming.

Table 5: Yield gaps calculated by different meta-analyses (category 'tubers')

Study	*Crop*	*Yield gap*
Eltun et al. 2002	Potato	-15%
Mäder et al. 2002	Potato	-36-42%
Badgley et al. 2007	Starchy roots (developed countries)	-11%
de Ponti et al. 2012	Roots/tubers (global average)	-26%

How do European yields compare?

Work with farmer innovation groups within OK-Net Arable has gathered data about the 14 organic farmer groups involved (located in 10 countries). All groups are formed from members who are a mix of new entrants and experienced organic farmers, and most groups include farmers who have farmed organically for over 10 years. The information below presents the average yields for each crop type recorded by the farmer groups, taken directly from the report *Description of farmer innovation groups*:

Wheat: In Bulgaria the reported variation in yields across the group ranges from 0.3 to 8t/ha. Excluding this group, yields range from 1 to 6t/ha with a likely average somewhere around 3t/ha.

Barley: The yield range is 1 to 7t/ha although only Belgium reaches yields that high with most groups reporting yields between 1.5 to 6.5t/ha.

Triticale: The picture is similar to barley with an overall range in yield between 1t/ha and 9t/ha. Again it is only the Belgian group that reports such high yields with the five other groups growing the crop failing to exceed 6t/ha. The lowest yielding group are BASE-ABC in France who yield as low as 1t/ha.

Rye: The range of yields is less variable (1.2-6.5 t/ha) with the highest yields from Sjaelland in Denmark, and the lowest in Bulgaria.

Spelt: Yields range from 0.8 to 5.5 t/ha with Hungary yielding highest and Bulgaria yielding lowest.

Oat: Yields range from 1.6 t/ha to 6.5t/ha with Vejle, Denmark having the highest yield and Estonia having the lowest yield.

Maize: Crop yields range between 0.8 and 15t/ha with Schlägl, Austria reporting yields of 10-15t/ha while Bioselena, Bulgaria reported yields of only 0.8 to 2.5 t/ha.

The only root crop grown by more than one group is potatoes and yields for these vary drastically in the Belgian group from 15 to 40t/ha. Yields are less varied in Austria (Schlägl), ranging from 15 to 25t/ha.

Faba bean: Yields vary from 0.5 to 5t/ha across all groups. The lowest yielding group farms in Bulgaria while the highest yielding group is Sjaelland in Denmark. Pea yields are less variable than faba bean yields, ranging from 1 to 4.5t/ha. Vejle Denmark has the highest yields, while RotAB, France has the lowest. Estonia also has quite low yields in comparison with the other groups.

Soya bean: Yields range from 0.5 to 4t/ha with a relatively small range of yields within each group. Hungarian yields are lowest, with both French groups yielding highest.

Grass/clover: yields between 5 and 12t DM/ha have been reported across the groups, with Belgium yielding highest and Schlägl in Austria yielding lowest.

Lucerne: Yields vary widely from 0.5 to 15t DM/ha. The Bulgarian group has the lowest yields while the highest yields are from the Italian group but there is a wide range of yields reported from this group of 4.5 to 15t DM/ha.

Table 6: UK Organic arable farm crop data (t/ha)[4]

Crop	Farm	2010	2011	2012	2013	2014	2015
First Winter wheat	1	5.5	4.2	2.4	3.8	3.8	3.2
	2	4.6	4.5	3.0	3.0	4.1	5.5
	4	3.5	3.8	3.0	2.7	5.1	4.4
	5			3.2	4.1	3.8	6.9
First W and S. wheat	3	3.4	3.0	2.4	2.6	2.6	3.2
Spring wheat	5			1.6	3.2	3.5	4.4
Second S. barley	4	4.5	3.6	1.9	3.9	2.2	3.8
W/S oats	2		5.5	5.7	4.5	3.7	4.2
Winter beans	1	3.3	3.4	1.1	3.8	3.2	4.6
	5			1.6	2.0	3.7	6.0

How do your yields compare?

Variation in yield is likely to be due to physical variations, i.e. climate and soil, and differences in management practices. Although there do not appear to be any clear trends in terms of climatic zones, northern temperate groups from Belgium and Denmark tend to achieve the highest cereal yields, while groups based in Bulgaria and Estonia tend to have lower yields. Though the highest yields achieved are comparable with conventional yields (particularly for grain legumes) there is a much bigger spread and greater variation.

The data suggests a need to improve yield performance and stability. A similar picture can be seen in some recently collated data from 5 UK organic arable farms (Table 6) representing a wide range of soil types. It also shows extreme variability for all crops, and reported yields of approximately 50% that of conventional yields for wheat.[4] All the data collated points towards the possibility of improving average yields through knowledge exchange aimed at improving agronomic practices. This highlights the value of the OK-Net Arable project and reiterates the importance of organic practices being combined with ecological, social and technological innovations.

References

1. Cullen B, Amos D, Padel S (2016). OK-NET Arable Deliverable D.2.1 Description of farmer innovation groups. Available at: http://www.ok-net-arable.eu/images/OK_NET_WP2_D2_1_final_-_Description_of_farmer_innovation_groups.pdf
2. Niggli U et al. (2016). OK-NET Arable Deliverable D.3.1 Description of farmer innovation groups. Available at: http://www.ok-net-arable.eu/images/OK_Net_WP3_D3.1_final.pdf
3. Lampkin, N.H et al. (2015). The role of agroecology in sustainable intensification. Report for the Land Use Policy Group. Organic Research Centre, Elm Farm and Game & Wildlife Conservation Trust. Available at http://www.snh.gov.uk/docs/A1652615.pdf
4. Measures M (2016). As presented at UK OK Net Arable group meeting.

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