European Organic Farming Research; the need focus on “Eco-functional Intensification”

Carlo Leifert
Nafferton Ecological Farming Group (NEFG), Nafferton Farm, Newcastle University, UK
Contents

1. Priorities - EU Organic Farming Research
2. Definition “Food Security”
3. Challenge – 9 Billion people
4. Global trends in agriculture
   - Crop yields
   - Resource use (NP-fertilisers/water/pesticides)
   - Resource use efficiency
5. Factors limiting crop yields in the future
   - Availability and cost of NPK-fertilisers
6. Strategies to improve “Food Security”
7. Barriers for “Ecofunctional intensification”
EU Organic farming R&D

FP5  Environmental impact (e.g. Blight-MOP)

FP6  Food Quality (e.g. QualityLowInputFood)

Standard development (Organic Revision)

FP7  Breeding and management innovations to improve robustness/resource use efficiency
  • QualityLowInputBreeds
  • NUE-crops

EU Horizon 2020     Food Security

IFOAM  Ecofunctional intensification
Food security

“The ability to provide enough food of high quality for humans through sustainable methods of production, processing, storage, transport, distribution, trading and retailing”

Sustainability in this context means without

- negative impacts on the environment,
- reliance on non-renewable resources,
- an erosion of current ethical standards

while ensuring

- fair economic returns to all food chain stakeholders
- flexibility to meet the challenges of global change
How can we produce enough food of high quality for 9 Billion people in a sustainable way?
Amount (kg) of cereal (corn-equivalents) necessary to produce 1 kg of livestock products

The diagram shows the amount of cereal required to produce 1 kg of different livestock products:

- 雞卵 (chicken eggs): 3 kg
- 鶏肉 (chicken meat): 4 kg
- 豚肉 (pork meat): 7 kg
- 牛肉 (beef): 11 kg

The chart indicates that beef requires the most cereal to produce 1 kg, followed by pork, chicken meat, and chicken eggs.
Jeremy Grantham* (2012) 
Welcome to Dystopia! Entering a longterm and politically dangerous food crisis. GMO Quarterly letter July 2012

* Co-founder and Chief Investment Strategist of Grantham Mayo Van Otterloo (GMO), a Boston-based asset management firm

“Anyone who believes exponential growth can go on forever in a finite world is either a madman or an economist”

Kenneth Boulding, economist
Total global cereal production

Total global use of nitrogen, phosphorus and area of irrigated land

Total global pesticide production and imports

Tillman et al. (2002) Nature 418, 671-677
Diminishing returns of fertiliser applications

Global cereal yield (t ha⁻¹)

N-efficiency of cereal production (t cereal/t fertiliser)

Declining resource use efficiency

Agricultural intensification over the last 40 years is estimated to have resulted in:

- a 2 fold increase in global food production\(^1\)
- a 5-7 fold increase in mineral NPK use\(^1\)
- resulting in a 2-3 fold reduction in nutrient use efficiency of crop production
- 2-3 times as much NPK is needed to produce a kg of food than 40 years ago

\(^1\) Hirel et al. (2007) *Journal of Experimental Botany* **58**: 2369-2387
Why has nutrient use efficiency (NUE) decreased?

- semi-dwarfing genes were introduced into wheat to reduce straw length and lodging risk
- semi-dwarfing genes also reduced root length/root system size and thereby nutrient uptake efficiency

Will it be possible to increase yields in conventional farming?

Rothamsted Research, BBSRC Institute, UK

Target: 20 t ha\(^{-1}\) wheat by 2050

Method: GMO-technology + more inputs

Exhibit 1
Crop Yields (5-year moving average)
Wheat – France, Germany, United Kingdom; Rice – Japan

Source: UN Food and Agriculture Organization  As of 12/31/10
What will limit crop yields in the future?

Availability and costs of:
- Nitrogen (N) = energy
- Phosphorus (P)
- Potassium (K)?, other minerals and WATER
Energy use – CO$_2$ emissions

Mineral N-Fertiliser

• 1 kg Nitrogen-fertiliser = 36,000kJ = 1 L fuel
• 1 kg nitrogen fertiliser ($\text{NH}_3\text{NO}_3$) results in
  = 2.38 kg CO$_2$ (equivalents of CO$_2$, CH$_4$ and N$_2$O)
• UK Farm level = 100 ha cereals x 200 kg N/ha/annum
  = 20,000 Litre fuel used
  = 47,600 kg CO$_2$ into the atmosphere

• European level = 11 Million t N/annum*
  = 11,000 Million Litre fuel used

  www.fertilizereurope.com
Energy requirement in agricultural system (world average) in KJ/kg

<table>
<thead>
<tr>
<th></th>
<th>Nitrogen</th>
<th>Phosphate</th>
<th>Potash</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>69,530</td>
<td>7,700</td>
<td>6,400</td>
</tr>
<tr>
<td>Packaging</td>
<td>2,600</td>
<td>2,600</td>
<td>1,800</td>
</tr>
<tr>
<td>Transportation</td>
<td>4,500</td>
<td>5,700</td>
<td>4,600</td>
</tr>
<tr>
<td>Application</td>
<td>1,600</td>
<td>1,500</td>
<td>1,000</td>
</tr>
<tr>
<td>Total</td>
<td>78,230</td>
<td>17,500</td>
<td>13,800</td>
</tr>
</tbody>
</table>

(Gellings and Parmenter 2004)
Proven global reserve: 1,333Gb: 45.7 years-consumption of 2009
(BP, 2010)
Nitrogen, population growth and emissions

World population and agricultural surface vs Fertilizer Nitrogen and NO$_x$ emission (UNESCO-SCOPE, 2007)
Why will Phosphorus become a bottleneck for productivity?

Phosphorus (P) fertiliser is a mined mineral

- Numerous scientific studies conclude that phosphorus (phosphate rock) reserves-resources will be depleted in the 21st century
  - Pessimistic: in 30-40 years
  - More optimistic: in 70-80 years

- IFDC (International Fertilizer Development Centre) prediction: 300-400 years
  - Based on current consumption
  - Does the fertiliser industry and its lobbying bodies just want business as usual (avoid rationing)?
Global Phosphorus use and reserves

World Phosphate Rock Reserves by Country

Will these countries be reliable suppliers in the future

Relative energy, fertiliser, mineral and agricultural commodity costs (2000-2008)

(Source: Piesse and Thirtle, 2009)
What is the effect of running out of mineral P-fertiliser (example: UK wheat production)
Wheat yield Nafferton Farm - 2004

Yield (t ha\(^{-1}\))

Organic

Conventional
Nutrients limiting wheat yield in 1900 and 2000 and predicted 2100 yields without P-fertilisation

Yield potential associated with different nutrients:
- N
- P
- K
- Other

Estimated wheat yield potential (t ha⁻¹)

- 2 t ha⁻¹ in 1900
- 7.5 t ha⁻¹ in 2000
- 3 t ha⁻¹ in 2100
Wheat yield Nafferton Farm 2100*
* predicted

Yield (t ha\(^{-1}\))

Organic  Conventional
What are the solutions?
The main approaches available are:

1. **More efficient recycling** of NPK via
   - animal and green manures,
   - crop residues, food processing waste
   - communal and domestic organic waste
   - human toilet waste/sewage

2. **Reduction of losses** of fertiliser from soils

3. **Breeding/selection** of more nutrient (especially N and P) efficient crop varieties

4. **Diet change** (less meat, dairy products and eggs in the human diet)
Closing the nitrogen (& other nutrient) cycles

- N\(_2\) atmosphere
- N-fertiliser manufacture
- N-fixation by legumes
- NH\(_3\)/NO\(_3\) soil
- N\(_{\text{organic}}\) crop biomass
- Landfill
- Incineration
- N\(_{\text{organic}}\) manure
- Livestock
- Sewage treatment works
- N\(_{\text{organic}}\) Organic waste
- N\(_{\text{organic}}\) Night soil
- Food processing/consumption
- CO\(_2\), CH\(_4\)
Can conventional farming deliver food security?

- **High yields** in conventional systems rely on **mineral NPK fertiliser inputs** and are **not sustainable**
  - Mineral **N-fertiliser** manufacture is estimated to account for 10% of total greenhouse gas emissions from agriculture
  - Mineral **P-deposits** will be depleted in 30-100 (300?) years

- **Without mineral P-inputs** yields in conventional farming will decline by more than 50%

- **In the future** mineral fertilisers will need to be replaced by
  - **organic fertilisers** made from both **agricultural and domestic/communal organic waste** (= recycling of NPK)
  - the use of **legume crops** to increase **N-inputs** into soils

- **Currently mineral NPK fertilisers are still too cheap**
  - BUT mineral fertiliser prices have increased more than 8-fold in the last 10 years
Can organic farming deliver food security?
Conventional management

Organic management

Nafferton Factorial Systems Comparison experiments
Experimental Design

Nafferton Factorial Systems Comparison Trial
Nafferton **factorial** production systems comparison trial – experimental design

- Rotation design (4)
  - Non-diverse (2): 2 years grass/clover 6 years cereals, 1 year potato/vegetables
  - Diversified (2): 3 years grass/clover, 2 years cereals 2 years potato/vegetables, 1 year faba beans)

- Crop protection (2)
  - Conventional (pesticides used to farm assured standards)
  - Organic (according to soil association standards)

- Fertilisation (2)
  - Conventional (pesticides used to farm assured standards)
  - Organic (composted manure inputs only)

- Replicate blocks (4)
- Replicate experiments (4)

Total area: 6 ha
Effect of fertilisation and crop protection on the wheat yield (average of 4 seasons)

Grain yield (t ha\(^{-1}\))

- **Conventional**
  - P<0.001
- **Organic**

Crop protection

Grain yield (t ha\(^{-1}\))

- **Conventional**
- **Organic**

Fertilisation

P<0.001
Wheat yield Nafferton Farm - 2004

Yield (t ha\(^{-1}\))

- Variety: Malacca
  - Typical short straw
  - UK variety

Organic vs. Conventional
Wheat - Yield (2005)
Effect of using varieties adapted to organic systems

Variety

Yield (t/ha)

Malacca
Pollux
Wenga
Greina
Wheat - Yield (2005)
Effect of using varieties adapted to organic systems (longer straw!, higher NUE?)

Yield (t/ha)

Malacca  +6%
Pollux  +15%
Wenga  +33%
Greina

Dark Green colour: standard fertility management
Light Blue colour: improved fertility management
Wheat 2005 - Protein content
Effect of using varieties adapted to organic systems

Protein (%)

- Malacca: 9%
- Pollux: 12%
- Wenga: 12%
- Greina: 12%
Effect of fertilisation and crop protection on the potato yield (average of 4 seasons)

**Crop protection**

- Conventional: ~45 t ha\(^{-1}\)
- Organic: ~40 t ha\(^{-1}\)

**Fertilisation**

- Conventional: ~50 t ha\(^{-1}\)
- Organic: ~45 t ha\(^{-1}\)

Both differences are statistically significant at P<0.001.
Effect of fertilisation and crop protection on the **cabbage** yield (average of 4 seasons)

![Bar chart showing the effect of crop protection on cabbage yield.](chart1)

- **Crop protection**
  - Conventional: [Value]
  - Organic: [Value]

![Bar chart showing the effect of fertilisation on cabbage yield.](chart2)

- **Fertilisation**
  - Conventional: [Value]
  - Organic: [Value]

*P < 0.001* for both fertilisation and crop protection.
Effect of fertilisation and crop protection on the **onion** yield (average of 4 seasons)

![Graph showing the effect of fertilisation and crop protection on onion yield.](image)

- **Crop protection**
  - Conventional: Red bar
  - Organic: Green bar
  - NS: Not significant

- **Fertilisation**
  - Conventional: Red bar
  - Organic: Green bar
  - NS: Not significant

**yield** (t ha\(^{-1}\) FW)
Can organic farming deliver food security?

• **Crop yields** in organic farming systems are lower
  – by up to **40%** in arable crops such as cereals/potato
  – yields in many horticultural crops are only slightly lower

• There is **great potential to increase yields** in **organic farming** systems by **optimising/increasing organic fertiliser inputs regimes**
  – Evidence from **long term trials in China** suggest that when used at **the same mineral input level**, mineral and organic fertilisers (e.g. manure) will produce **similar yields**

• There is increasing amount of organic waste !!!!!

• So what are the barriers for “**eco-functional intensification**” of organic crop production
Barriers for “eco-functional intensification”

- **Organic standards/legislation** which
  - restrict “imports” of fertility (principle of on-farm sustainability)
  - prohibit the use of certain organic wastes (night soil, sewage, animal processing waste) as fertiliser

- **Environmental legislations** which
  - restricts organic fertiliser inputs to 170 kg N ha\(^{-1}\) annum\(^{-1}\) although the nitrate leaching and P-run-off risk differ greatly between organic fertilisers
  - requires farms to have waste management licences to import urban organic waste onto farms
Issue associated with the “eco-functional intensification” of organic crop production

• **Food safety**
  – Is there an increased risk from food pathogen, heavy metals, other pollutants when using organic waste based fertilisers?

• **Consumer perceptions**
  – will organic consumers accept the use of night soil/sewage based fertilisers?

• **Crop health and nutritional quality**
  – will pest, disease and weed pressure increase?
  – will the nutritional value of crops decrease?

• **Environmental impact**
  – Will nitrate leaching and P-run off increase?
  – Will greenhouse gas emissions from fertiliser increase?
  – Will **energy use** increase further?
Energy consumption in conventional vs organic crops (per unit area)

(Manchester UK, 2000)
Energy consumption in conventional vs organic crops (per unit product)

- Winter wheat
- Potatoes
- Carrots
- Cabbage
- Onion
- Calabrese
- Leeks

(MAFF UK, 2000)
We need to extensify organic animal production!!!!
Amount of cereal (corn-equivalents) necessary to produce 1 kg of livestock products
Thank you