Wheat and Oilseed Rape Yields – Factors with the greatest impact and why GM will not make a difference

GM FREEZE
the campaign on GM food, crops and patents

10 January 2013

> "*Soil management may have suffered through change being driven by what is technically possible and economically attractive rather than agronomically appropriate. New cultivation equipment and drills have saved time and fuel, and delivered effective establishment. However the industry has been on a learning curve, during which yields may have suffered in the short term. There has been little emphasis on soil management studies, undertaken and interpreted in the context of today's production systems. The trend towards heavier machinery is a particular concern. The extent and impact of soil compaction at or below sub-soiling depth needs to be quantified, along with the state of UK soils in terms of other measures such as under-drainage and organic matter content.*"
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> - HGCA 2012[1]

Introduction

It has been widely reported that the annual increment in the average yields of UK wheat and oilseed rape, expected as a result of traditional plant breeding bringing improved varieties to the market, have not materialised in recent years.[2] One report estimated that from 1988 to 2008, 88% of yield increase in wheat was due to plant breeding: there is "little evidence that changes in agronomy have improved yields".[3] The levelling off of annual yield increment has been attributed to the failure capitalise on the potential gains made through traditional breeding and has led to calls for new technologies to be developed, especially genetic modification (GM), to maintain the increment in annual yield averages.[4]

GM critics point out that the final yield and quality of a crop[5] is determined by the interaction of the variety's whole genome with the environmental conditions (eg, weather, soil conditions and fertility, weeds, disease and pest levels) present throughout the growing period and that a few additional GM traits will not automatically lead to a yield increase.

This briefing looks at why crops do not reach their genetic potential. It draws on research by the UK Home Grown Cereals Authority (HGCA) published in 2012[6] examining why current wheat and oilseed rape varieties are failing to achieve their genetic potential (as demonstrated by yields achieved in National List and Recommended List trials) when they are grown on commercial farms.

Yields

The varieties of wheat and oilseed rape currently available are capable of far higher yields than are being achieved by the majority of commercial farmers.

HGCA says that yields of wheat have "stagnated" since 1996. In the decade prior to this the increase in average yield for wheat was one tonne/hectare, but according to HGCA, *"Since then yields have stagnated despite the potential of new varieties increasing by 0.05 tonnes/hectare/year."* Average yield in the UK is around 8 tonnes/hectare. Yields from trials show the genetic potential of non-GM cereals could nearly double this if soil and other conditions are optimised.[7] However in the field optimal conditions are seldom present.

Average yields for oilseed rape fell from 1984-94, and afterward the annual increment has amounted to 0.075 tonnes/hectare/year since 2004.

Factors preventing crops reaching their optimum yield

The number of factors affecting each crop will vary from year, and every individual crop will have a different combination of factors (and severity). Some of these are impossible to predict when the crop is sown.

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Wheat
The HGCA report puts forward a number of reasons why wheat yields in the UK are not as high as their genetic potential would suggest they should be. It identifies the following significant in lowering yields:

- Lack of sunshine at critical periods of crops development (eg, when grains are filling).
- Heat stress caused by very high temperatures.
- Late sowing.
- Sub-optimal planting density.
- Soil pH outside the optimum range for wheat (ie, more acidic soil such as sand).
- Sub-optimal availability of nitrogen (application rates being strongly influenced by fertiliser prices and gross margins).
- Deficient soil availability of phosphorus and potassium can reduce yields by up to 0.006tonnes/hectare/year.
- Soil availability of sulphur can reduce yields by up to 0.4 tonnes/hectare.
- Failure to adequately control or prevent fungal pathogens (eg, take-all and septoria).
- Minimal tillage reduces yield immediately, and a decline of 0.004 kilogrammes/hectare/year is indicated.
- Deep soil compaction due to heavy machinery causes poor drainage and can reduce cereal yield 16% on average. HGCA says 15% of wheat fields are not regularly mole drained to alleviate deep soil compaction.
- Short rotations – growing wheat in successive years (second wheat) has a yield penalty of 10%, increasing to 14% in subsequent wheat crops.

Some factors can increase yields, like increased atmospheric concentration of CO_2 or early sowing, and the prioritisation of controlling Black Grass above all else may impact on yield by changing crop management practices.

HGCA says there is little evidence that trace element shortages have so far contributed to yield stagnation. However there is evidence that soil levels of manganese, copper and zinc have fallen in the last 30 years, and this could have implications for public health as trace elements in food mirror this decline. HGCA reports[8] that since the mid-1960s concentrations of these three elements in wheat grain have decreased in samples taken from the Broadbalk Wheat Experiment at Rothamsted without a reduction in concentrations in the soil, suggesting that remaining nutrients may be less available for plants to take up.

Economic and political factors also affected wheat yields in the past two decades. Falling grain prices from 1996 to 1998 influenced the amount and timing of inputs, and therefore reduced overall yields, as farmers planned to maximise gross margins rather than yield. The Common Agricultural Policy can also have an effect, for example set-aside increased average wheat yields because the least productive land was taken out of production. Another important factor in the stagnation in yield is that plant breeders have been targeting breadmaking quality in their programmes rather than yield increase *per se*.

Many factors can come together in determining the final yield of a wheat crop. The quality of the soil and agronomy are crucial factors in yield, including dealing with and preventing soil compaction, lengthening rotations by avoiding successive wheat crops, introducing break crops to reduce weed and disease pressure, building soil fertility and changing crop agronomy (eg, planting density). GM technology is not needed to tackle any of these problems, and research and development should concentrate on creating conditions that allow wheat varieties to attain more of their existing genetic potential.

The GM wheat project currently underway in the UK is focused on genetically modifying Spring wheat to produce semiochemicals designed to repel aphids,[9] although even pro-GM farmers question the merits of this project[10] because aphid control is not a major problem in Spring wheat. GM wheat trials in Australia are focussed on altered carbohydrate content and nutrient uptake.[11]

Other GM wheat experiments have included traits for herbicide tolerance and altered gluten content. Drought tolerance, saline tolerant and nitrogen fixing wheat have been promised by the GM industry and others for years, but the complexities of the genetics involved are beyond genetic engineers to date and may not automatically increase yields if this is overcome.[12 ,13 and 14]

The safety of the GM techniques being employed in trials has been questioned.[15 and 16]

Even with several GM traits, wheat varieties could still perform well below optimum if their natural parent genome was not well adapted to the conditions present throughout the growing cycle.

Oilseed rape
Analysis of National List and Recommended List trial yields suggest that an annual yield gain of 0.048tonnes/hectares/year should be coming through as a result of new varieties of Winter oilseed rape coming onto the market. HGCA says that prior to 2004 uptake of new varieties was poor as farmers preferred older varieties with easier management and handling characteristics. Since 2004 there has been a greater uptake of new varieties, and the gap between farm yield and potential yield has narrowed.

The HGCA report identifies the following factors as important in decreasing yield in Winter oilseed rape:

- Heavy rain in April.
- Soil compaction.
- Sub-optimal application of nitrogen in the Spring.
- Short rotations between rape crops can reduce yields by up to 12% if the gap is only one year (4% for two years and 3% for three years).
- Sulphur deficiency in soil reduced national yield by up to 0.4tonnes/hectare in the early 1990s, although recently the proportion of fields receiving sulphur-based fertilisers has risen to 60-70%.
- Aphid-borne Yellow Turnip Virus can decrease yields 26%, but insecticide use has increased since in the 2002 including seed treatments using neonicotinoids[17] and other active ingredients.
- Weed pressure from chickweed and Black Grass can reduce yields by 0.5%, although increasing use of herbicides has kept yield reduction to a minimum.
- A shift to minimum tillage although saving cost, conserving moisture and potentially improving Black Grass control, is likely to have a detrimental effect on yields.

Other factors can increase yield, including increased sunshine enhancing pollination and photosynthesis and dry, cold and sunny weather in December, which probably suppresses some pests and diseases, such as phoma.

Oilseed rape yields are strongly influenced by weather at particular points in the growth cycle, short rotations, the quality and fertility of the soil, several agronomic practices including minimum tillage and some pests. GM traits have no influence over these.

Herbicide tolerant (HT) oilseed rape (with tolerance to glyphosate and glufosinate ammonium) has been developed for Europe but has not been approved for commercial cultivation. Large-scale UK trials in the early 2000s found that HT Winter and Spring oilseed rape with tolerance to glufosinate ammonium would significantly reduce overall weed presence and weed seeds. These form the base of the farmland ecosystem, so birds and insects higher up the food chain would be harmed[18] by lack of food and cover. Applications to grow these crops commercially were therefore refused. GM HT oilseed has been adopted in North America where it has created serious contamination problems for non-GM and organic growers, as well as causing problems controlling GM volunteer oilseed rape plants in other HT crops.[19]

The Way Forward
Yields of wheat and oilseed rape are the products of the genetic makeup of the seed, the quality of

the soil, the quality of the husbandry used, the presence or absence of pests, disease and weeds and the weather conditions throughout their growing cycles.

In September 2011, after one of the driest periods ever recorded, UK farmers were making decisions about which varieties to plant to be harvested in 2012. The crops they sowed ended up growing through one of the wettest summers ever recorded in which soils were saturated for weeks in succession to the point that harvesting became a major problem. The soil compaction caused during harvesting in extremely adverse conditions could well have an impact on future yields according to the HGCA's report. Crop genetics are important, but optimum yields depend on the biotic and abiotic challenges the crops faces and the skill of farmers in creating the best possible conditions in the circumstances that prevail.

The HGCA report shows how the genetic potential of crops can be nullified if other factors are against the crop or ignored. If variety selection means that the crop is not well adapted to the prevailing conditions yield will be lower. GM varieties are just conventional varieties with one of two GM traits spliced in. If their whole genome is not right for the conditions, yields will be lower. GM traits will only help if they deal with some of the challenges present at the time. If not they can divert energy from other important functions in the plant and could even reduce yield.

Farmers can never second-guess what will happen to their crop once it is sown, as the 2011/12 season in the UK clearly illustrates. Often the same varieties of wheat and oilseed rape are grown over large areas. This means that the gene pool available to cope with biotic and abiotic stresses is very narrow (compared to a forest ecosystem for instance).

Increasing the number of varieties grown will help produce crops that are better able to adapt to the prevailing conditions. Planting a seed lot made up of several varieties has also been shown to reduce disease[20 and 21] and produce acceptable yields. Other cultivation systems, such as agroforestry where crops are interspersed with trees, have also been shown to be more resilient and produce acceptable yields from the whole system,[22] as well as providing a high level of environmental benefits and soil improvement.

The HGCA report clearly shows that plant breeding alone, and especially plant breeding to serve monocultural agriculture, can be limited by biological, chemical and physical constraints. The continuation of current practices could make matters worse. Agroecological approaches, such as mixed farming and agroforestry, place emphasis on diversity and enhancement of the soil to optimise its potential to produce many benefits (eg, water absorption, a water filtering habitat for biological control agents and enhanced fertility).

GM technology takes agriculture in the opposite direction and will have minimal impact in addressing the yield constraints identified in the HGCA report. GM may make some problems worse as it is designed to serve highly intensive arable monocultures (where crop rotation is minimal) and mechanised production systems, which produce the deep soil compaction among other problems.

Notes

[1] Knight S, Kightley S, Bingham I, Hoad S, Lang B, Philpott H, Stobart R, Thomas J, Barnes A and Ball B, 2012. *Project Report No. 502: Desk study to evaluate contributory causes of the current "yield plateau" in wheat and oilseed rape*

[2] Defra, July 2012**.** *Green Food Project Wheat Sub Group Report Themes, Tensions and Recommendations* (pdf)

[3] Mackay I, Horwell A, Garner J, White J, McKee J and Philpott H, 2011. "Reanalyses of the historical series of UK variety trials to quantify the contributions of genetic and environmental factors to trends and variability in yield over time." *Theoretical and Applied Genetics* 122; 225-238.

[4] Defra, 2012**.** *Op cit*

[5] Gurian-Sherman D, 2009. Failure to Yield. Evaluating the Performance of Genetically Engineered Crops (pdf). Union of Concerned Scientists

[6] Knight S, *et al*, 2012. *Op cit*
[7] *Farmers Weekly*, 15 February 2012. "Winning with wheat: Meeting the challenge of growing record-breaking crops**".** Conventionally-bred wheat varieties are capable of much higher yields than the UK average (around 8 tonnes/hectare). A yield of over 15 tonnes/hectare was recorded in the UK in 2011, just behind the world record of 15.637 tonnes/hectare in New Zealand in 2010. This is currently achieved using high inputs of artificial fertilisers, pesticides and, in some cases, irrigation.
[8] Knight S, *et al*, 2012. *Op cit*
[9] Rothamsted Research, 2012. *Wheat with environmentally sustainable pest management?*
[10] Guy Smith, a farmer in South East Essex, commented, "For me as a practical farmer, I spend less than £5/acre on insecticide sprays when growing wheat, so the economic benefits are not exactly exciting. But the main question I have is why are we spending a large chunk of our finite R&D budget on a crop no one wants to buy?"
[11] CSIRO, undated. "GM wheat and barley trial". OGTR application DIR099
[12] GM Freeze, 2012. *Nitrogen fixing cereals: No silver bullet*
[13] GM Freeze, 2008. *GM and Saline Tolerant Crops*
[14] GM Freeze, 2008, *GM and drought tolerance*
[15] Heinemann J, 2012. **"**Evaluation of risks from creation of novel RNA molecules in genetically engineered wheat plants and recommendations for risk assessment. (pdf)" Food Safety Institute
[16] Carman J, 2012. "*Expert Scientific Opinion on CSIRO GM Wheat Varieties*. (pdf)" University of Flinders
[17] Neonicotinoids have been closely linked with the reduction in bee populations. See PAN UK, 2012. *Sub-lethal and chronic effects of neonicotinoids on bees and other pollinators*
[18] Heard MS, Hawes C, Champion GT, Clark SJ, Firbank LG, Haughton AJ, Parish AM, Perry JN, Rothery P, Scott RJ, Skellern MP, Squire GR & Hill MO. 2003a. Weeds in fields with contrasting conventional and genetically modifies herbicide-tolerant crop – I. Effects on abundance and diversity. Philosophical Transactions of The Royal Society London B 358: 1819-1832
[19] See Farmer to farmer
[20] Finckh M R, Gacek E S, Goyeau H, Lannou C, Merz U, Mundt C C, Munk L, Nadziak J, Newton A C, de Vallavieille-Pope C, Wolfe MS, 2000. "Cereal variety and species mixtures in practice, with emphasis on disease resistance." *Agronomie* 20: 813-837.
[21] Phillips SL, Wolfe MS, 2005. "Evolutionary plant breeding for low input systems". *Journal of Agricultural Science* 143: 245-254
[22] Smith J, 2010. Agroforestry: Reconciling Production with Protection of the Environment - A Synopsis of Research Literature (pdf). Organic Research Centre