Plant Breeding and Crop Yields - Can we rely on GM to increase yield?

the campaign on GM food, crops and patents

May 2011

Summary

Proponents of GM crops claim that they yield more then conventionally bred ones[1]. However the final yield of any crop is ultimately decided by the conditions in which it is grown and how well adapted the variety's genome is to the conditions during the growing season - yield is not determined by handful of genes inserted by genetic engineers. Currently commercial GM crops are overwhelming genetically engineered with herbicide tolerant traits or insect resistance genes, which are agronomic in nature and only impact on yield when there are high levels of weed or pest pressure. Other factors, such as weather or a range of diseases, can impact on yield despite the presence of these GM traits.

The whole genome of every crop is therefore vital to its success or failure. Comparisons based just on the presence or absence of GM traits are not very helpful in determining the impact of GM traits on yields. The only reliable way to asses the impact of GM on yield is to compare yield between GM varieties and the same variety minus the GM traits (known as an isogenic comparison) under identical growing conditions. Yields for the same variety can vary enormously between sites and between years at the same site because their intrinsic potential to yield is so heavily influenced by the environment in which they are grown. Ideal conditions for highest potential yield are rarely seen in the real world.

Genetically modified plants are genetically altered to produce novel proteins or enzymes that require them to use part of the energy the plant gets from photosynthesis. In the absence of weeds and pests above a threshold when yields may be reduced, this effort is wasted and could result in lower yields (known as yield drag). The abundance of the insect pests targeted by GM crops is also variable and largely dependent on the weather or presence of predators or other biological control agents at different periods of the year. Pests may only be present one year in ten, and therefore the "built-in" insecticides in GM crops may be obsolete for 9 years out of ten.

Growing conditions are also strongly influenced by the wealth and knowledge of farmers – richer farmers with access to irrigation and fertilisers and those who have been trained often do better than farmers who do not have these advantages, even though they may be growing the same variety in the same area.

Claims that GM crops yield more than conventional crops must therefore be examined carefully to ensure that studies are comparing like with like. An inferior genome will nearly always perform less well than one very well adapted to the growing conditions in any one year with or without GM interventions.

Introduction

This briefing examines the often repeated claim that GM crops are needed to help feed the expanding world population and that they yield more than traditionally bred varieties. For instance The Foresight Report[2], published by the UK government in January 2011, suggested that GM technology had a crucial part to play in their projection that yields need to double by 2050 to feed a projected human population of 9 billion in a world stressed by climate change, resource shortages and the overriding to need to restore biodiversity and natural resources (the so-called "perfect storm"[3]). An earlier report by the Royal Society[4] made similar points and called for "sustainable intensification", which envisaged the use of GM technology.

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Both reports were at pains to emphasise that GM is not a "silver bullet" and would not solve the problems faced on its own, but pushed GM crops as "an essential tool in the tool box" that cannot be ignored.

However, based on the progress made with transgenic crops to date (which have contributed little to increased crop yields so far[5]), there is little evidence that GM crops will help increase yields to the extent claimed to be required (1.5% per annum growth for staple crops until 2050[6]). Agroecological approaches are the way forward in a world facing climate change, rising population, degraded biodiversity and natural resources and rising raw materials prices[7].

Wrong model

The model of the future upon which the Foresight Report's pessimism is based assumes that current meat and dairy consumption found in rich northern countries will be replicated elsewhere as *per capita* incomes increase. In such a future food consumption patterns would include a significant proportion of grain-fed meat and dairy products, despite very strong health and environmental arguments for countries in the Global South to avoid the lifestyle and diet choices made in northern industrialised countries[8] where the full public health implications of such choices are still becoming apparent.

There is no shortage of food in the world, nor should there be. The recent Green Economy Report by the UNEP[9] states that 4600 kcal of food is currently produced for every person on the planet, but only 2000 kcal per person are actually was available to eat because of wastage. In addition there is huge imbalance in consumption levels between rich and poor, which currently results in 925 million undernourished people[10], and 1,500 million overweight/obese adults over 20 years of age[11].

It is therefore more logical to address reducing losses and uneven distribution of calories than to attempt to squeeze more production out of agroecosystems already under great stress from current intensive agricultural practices[12].

Crop yields

The actual yield of any one crop in any one year is the product of its genetic make-up and how it responds to the environment in which it is growing, which can change very rapidly (for instance from drought conditions to water logging in a very short space of time). Different genetic traits may be important in determining yield in one year but not the next (eg, resistance to a fungal disease which varies in severity from year to year, so that some years it may be highly damaging to the crop but in others well below the threshold where harm occurs).

The intrinsic potential of conventionally bred varieties to produce very large yields if conditions are optimal was illustrated by a new world record set for wheat yield in New Zealand in 2010 – 15.636 tonnes per hectare[13], more than twice the EU mean yield in 2007 (excluding Czech Republic, Greece and the UK)[14]. Optimum environmental conditions are rare, so average yields will always be below the intrinsic potential of the genomes present in individual varieties.

GM traits and yield

The current generation of GM crops mainly have herbicide tolerance, insect resistance or combinations of both. These traits are primarily agronomic and are not targeted at increasing yield *per se*, but may do so indirectly when weed pressure or insect infestation reaches an economic threshold.

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Genetic modifications that could increase the intrinsic yields of crops, such as altering photosynthetic pathways or incorporation of nitrogen fixing into wheat, have been described as "high risk" by the Royal Society[15] and have not been possible so far. These types of genetic modifications are far more complex than the single GM traits seen so far in herbicide tolerant or insect resistant crops. The more complex changes to photosynthetic pathways may interfere with other biochemical processes in the plant in addition to the ones targeted by the genetic modification. Genetic modification of nitrogen fixation in cereals requires GM of both wheat and the symbiotic microbes found naturally in the roots of legumes and is therefore far more complex than anything achieved so far. GM nitrogen fixing may be 30-40 years away according to one scientist working in the field[16] if, indeed, it proves to be possible at all.

It is worth noting that genetic traits showing great promise in the lab, which may have been patented because of their potential, may not transfer successfully into a commercial variety:

> *"It is necessary to point out the commercial reality that few, if any, of the patents and applications in these lists will ever produce a financial profit. The most common reasons for this lack of success are unexpected additional costs of development or failure of the underlying science during the transfer from laboratory to field scale."* [17]

GM crop yield to date

A review of the performance of GM crops in the US (Gurian-Sherman 2009[18]) examined data on yields in the US and concluded that GM traits have made a comparatively small contribution to corn and soya yield increases since commercial growing commenced in the 1990s:

> *"Our review of available data on transgenic Bt corn, as well as on transgenic HT corn and soybeans, arrives at an estimated total yield benefit of about 3–4 percent for corn."*

And

> *"Corn yields over the past several decades have increased an average of about 1 percent per year – considerably greater than the increase that can be attributed specifically to GE. Corn yields have increased about 28 percent since Bt corn was first planted commercially (as determined by comparing the average yield for the five years preceding the introduction of Bt corn with the average yield over the past five years). But the 4 percent yield enhancement contributed by Bt varieties constitutes only about 14 percent of this overall corn yield increase, with 86 percent coming from other technologies or methods."*

One of the problems of assessing the impacts of GM traits on yields is that often the varieties under comparison have significantly different genomes and therefore are not strictly comparable. One variety may be better adapted to the prevailing conditions because of its background genetics irrespective of whether there are GM traits present. Gurian-Sherman (2009[19]) points out:

> *"Ideally, the background genetics of the GE and non-GE varieties should be identical except for the presence or absence of the transgene. In practice, however, such complete genetic identity is not possible, though it can be approximated in so-called 'near-isogenic' (NI) varieties."*

Yield trials in recent years

This section illustrates the difficulties involved in comparing GM and non-GM varieties and of trying to apportion yield response to particular GM traits.

One source of information about the yield of different crop varieties is state university crop trials in the US. Results from recent university-run crops trials of soybeans, maize and canola demonstrate that the presence of GM traits for herbicide tolerance and insect resistance is no guarantee of higher yields, and that external stresses on the plant have far greater impact on yield than the presence or absence of GM traits.

Below we summarise three sets of university trial data for canola (University of Idaho), corn (University of Iowa) and soybeans (University of Michigan). In all these trials none of the varieties tested can be confirmed to be near isogenic to other ones in the trail so they cannot be definitively used to show how GM and non–GM varieties compare in yields.

A. University of Idaho winter canola and deep furrow trials 2009
(see www.cals.uidaho.edu/brassica/Variety-trial-info/Report%20WVT%2009.pdf)

These trials were conducted independently of the companies that supplied the seed for testing. The companies paid a fee to enter varieties in the trial, although these did not cover the full costs, which were made up by the institutions that conducted them.

Nineteen *Brassica napus* canola or rapeseed cultivars and breeding lines plus three control cultivars (‘Dwarf Essex’ industrial rapeseed (*B. napus*), ‘Bridger’ industrial rapeseed (*B. napus*), and ‘Salut’ canola (*B. rapa*)) were planted in 2008 at eight locations. One third of the cultivars entered (7 in total) were GM Roundup Ready types, and these have “RR” in their names.

Two trials were abandoned because dry conditions led to poor germination.

Regional variety trials
This trial was set up to access the performance of the Winter canola varieties in the climate of the Pacific NW of the USA.

There were considerable differences in the mean yield achieved between the different trial sites, ranging from 2337 lbs/acre to 4426 lbs/acre (an 89% difference between lowest and highest), clearly illustrating how the environmental difference between sites affected all the varieties tested. Yields of all the varieties tested ranged from a low of 1880 lbs/acre to a high of 4703 lbs/acre across all the trial sites.

The trial report says:

> *“Work needs to continue to develop cultivars that are better adapted to direct seed systems and that have increased winter hardiness in the seedling stage to allow later planting during dry falls and in recrop situations”.*
>
> *“As in previous years these trials demonstrated that even with timely late summer rains, establishing winter canola can be difficult at some sites, especially in direct seed situations. In fact, both direct seed sites were abandoned this year because of poor emergence.”*

Performance of RR varieties
Seven RR varieties from four companies were tested (four from Monsanto, one from DL Seeds, one from Crop Plan Genetics and one from Wilbur Ellis Co). The RR varieties average yield was 3475 lbs/acre compared to the conventional varieties 3675 lbs/acre (5.7% higher).

The results show that only one of the RR varieties made it into the top ten varieties for yield (HyCLASS 154W RR from DL Seeds). The other RR varieties occupied positions 11, 15,16,18,19 and 20 out of a total of 22. The better performance of the DL Seeds variety may be explained by the performance of the company's non-GM varieties, which finished first and second in the ranking, suggesting that their gene pool for canola breeding may be better adapted to this region of the USA than those of the other companies taking part.

Deep furrow trial trials
This trial was on a smaller scale. The purpose was to test the growing system to see if it led to earlier planted varieties establishing better and making better use of the available soil water. The average yield at the one site used was only 2594 lbs/acre, compared to 3609 lbs/acre in the main trials. In this trial Monsanto's DKW.45-10 RR (GM) came out best, and a high non-GM performer from the main trial came last of five varieties (12.9% higher than the mean). The research team put forward explained this reversal saying, *"DKW 45-10 is a moderately early cultivar, and this attribute might have given it an advantage* [in this trial at this site]."

They also suggested that, *"The relative branching ability of each variety could have had an effect on yield as well, since the trial utilized extremely wide row spacing."*

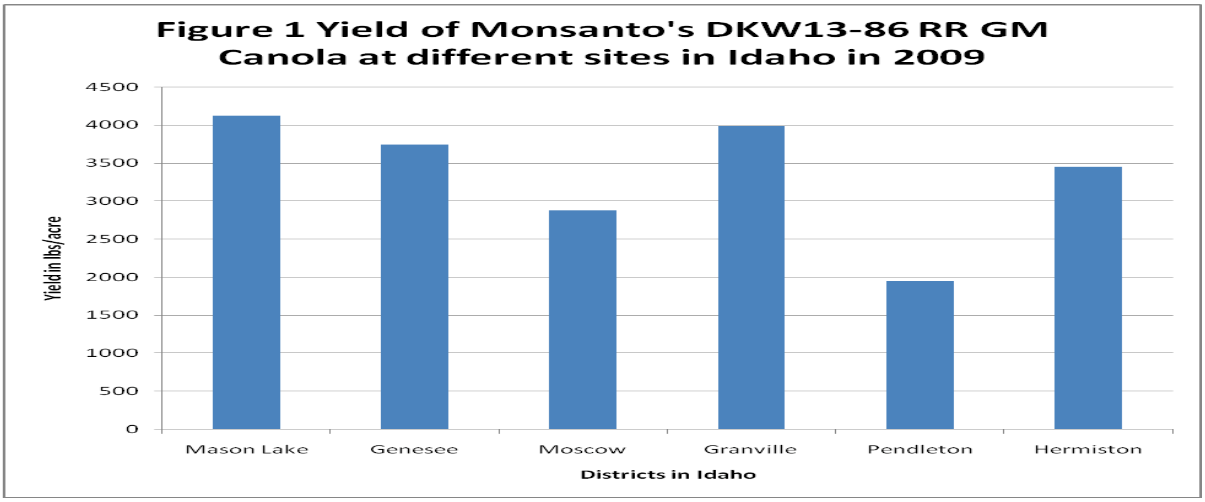
The explanation from the researchers for the good performance of the RR variety was based on its traits for earliness and branching, neither of which is affected by the presence of the RR gene.

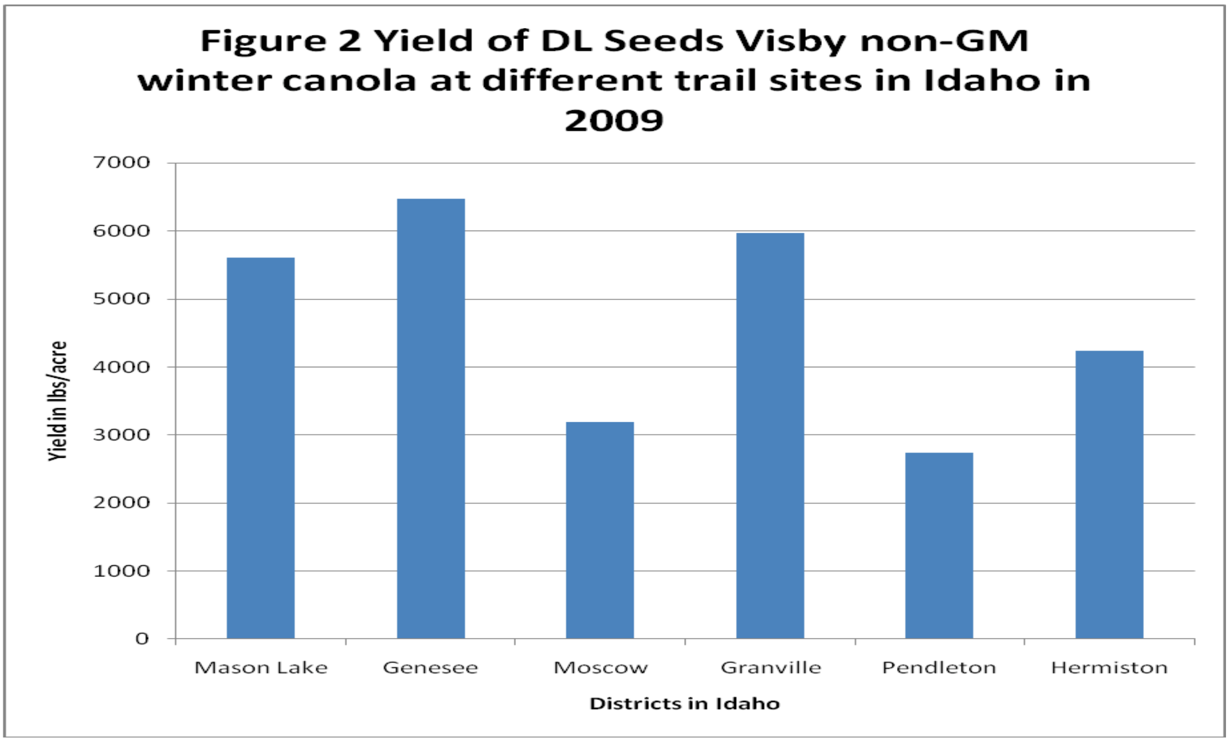
Incidentally DKW.45-10 RR performed much better in the main trial than in the deep furrow trial - 2928 lbs/acre in the deep furrow trial against 3418 lbs/acre in the variety trial (16.7% higher).

Variation between sites for varieties
The trial results show big differences in yield for the same varieties between the six sites:

- One non-GM variety varied by 136% between the lowest and highest yielding site (Figure 1).
- One Monsanto RR variety varied by 112% between the highest and lowest yielding site (Figure 2).

These results emphasise the importance of how well a variety copes with the conditions at each site, rather than whether or not a GM herbicide tolerance gene is present.





Conclusion

These trial results illustrate that the presence of RR genes in canola do not guarantee a high yielding variety, and it is the background genetics of the variety that counts most. Generally the RR varieties performed worse than the conventional (5.7% lower yield on average).

It is worth noting that the RR is promoted as the key breakthrough for zero tillage systems of cultivation because weeds can be controlled after the crop germinates. However for the Winter canola varieties in the Pacific North West of the US tested in these trials, the ability to germinate and survive when soil moisture is low seems as important as any other trait.

B. 2010 Iowa corn performance test 2010

(see www.croptesting.iastate.edu/corn/reports/corn_2010_finalreport.pdf)

Every year Iowa State University carries out performance trials for corn (maize) varieties in a number of state districts and several locations in each district. The 2010 trials included the latest SmartStax GM maize varieties.

The result for each variety entered into the trials is compared to the average for the whole district. For the purposes of this analysis, the yield as percentage of the district average is compared as well as average yields for particular varieties tested. Most of the varieties tested in the Iowa trials were GM hybrids with either single traits (herbicide tolerance or insect resistance) or stacked traits[1]. Twenty-three out of 230 hybrids tested were non-GM.

The 2010 performance test was therefore primarily a comparison of GM varieties, so it is not surprising that a GM variety was the best performer in each district. However as there no information regarding the parents of the hybrids was given it is impossible to assess the significance of the GM traits compared to the background genetics in each variety.

[1] Stacked GM varieties include more than one GM trait often herbicide tolerance genes in combination with insect resistance.

SmartStax varieties were tested and were easily identifiable in the results from information provided in the report. This maize has eight GM traits in total – six for insect resistance and two for herbicide tolerance. The Iowa performance trial included 11 varieties of SmartStax, produced by four companies, which were trialled at 22 sites across six districts. The 23 non-GM varieties tested were produced by 7 companies.

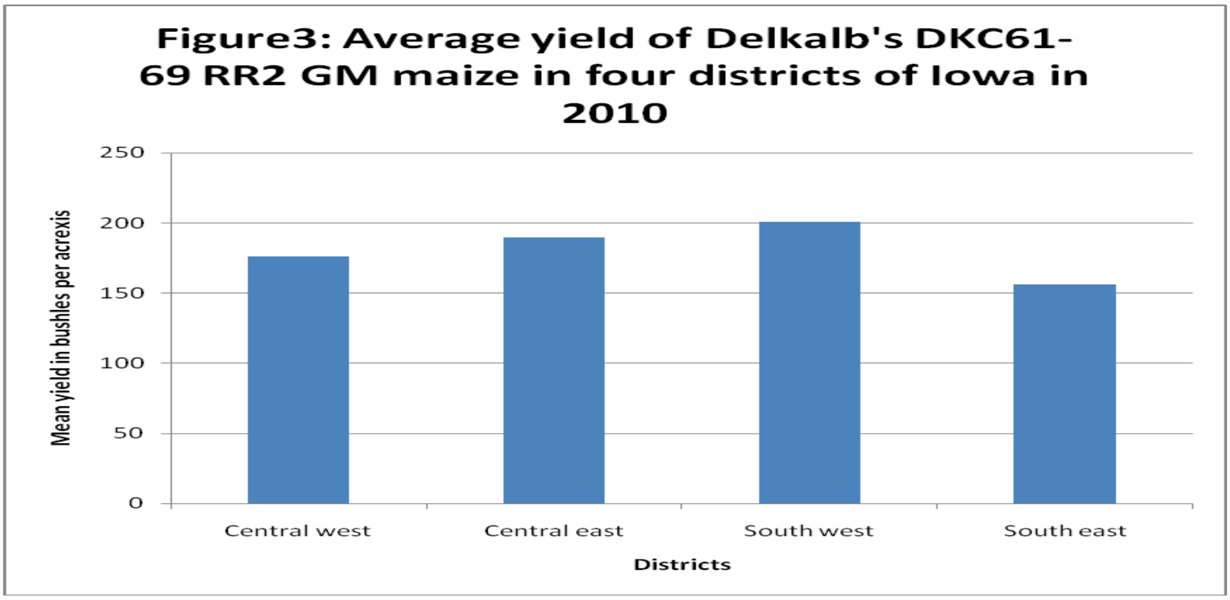
SmartStax's performance 2010

The overall performance of all the SmartStax varieties was poor compared with the other varieties trialled – on average SmartStax yielded 5.75% less than the district average (see Annex 1 below).

The yield as a percentage of district average for non-GM varieties is shown in Annex 2. These performed far better than SmartStax and came out just 0.4% below the district mean on average. Overall GM varieties which were not SmartStax performed best across the trials.

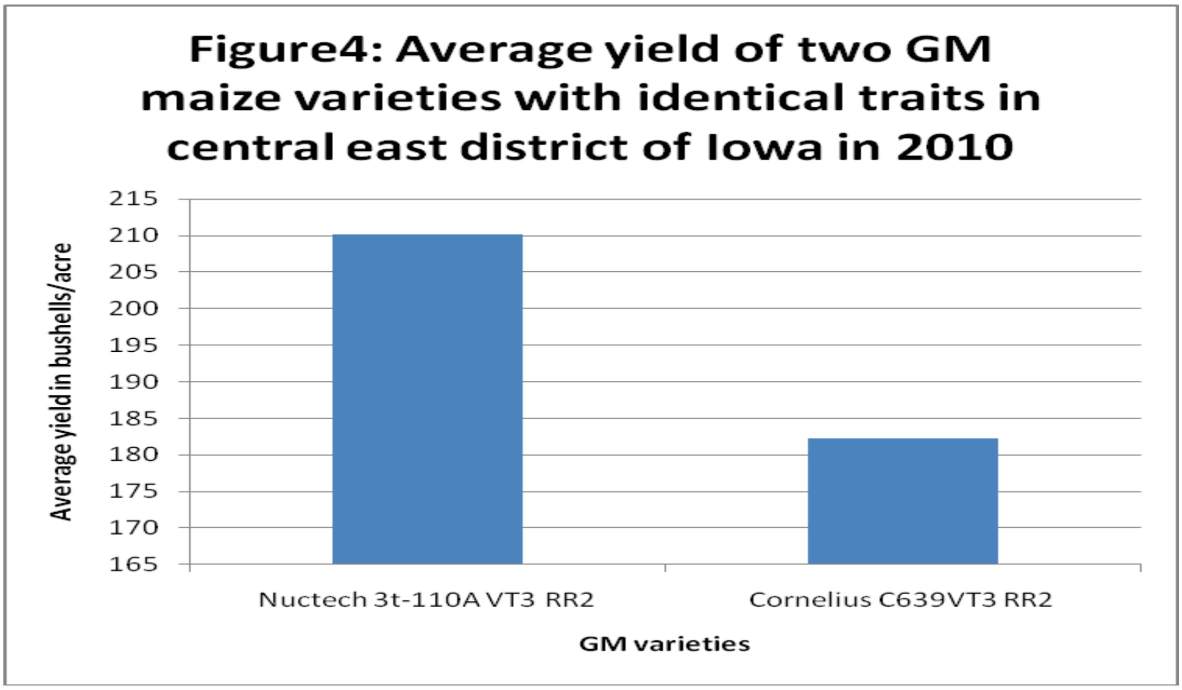
The actual yields from SmartStax compared poorly with the non-GM varieties. The 24 trials of SmartStax average 168.7 bushels/acre, compared with 176.3 bushels/acre for the 46 trials of non-GM maize tested (4.3% lower).

The performance of individual varieties varied greatly between different districts. For example Delkab's DKC61-69 (GM) varied between 156.4 bushels/acre in the SE district and 200.6 bushels/acre in the SW district – a 22% difference (Figure 3), clearly showing the influence of local condition on the final yield.



The variation in yield for the same variety is considerable, even in the same district (Figure 4), emphasising that crop performance is heavily influenced by conditions during the growing season. The highest yielding site (Hubbard) yielded 23% more than the lowest (Ames).

To illustrate the point that GM traits are no guide to final yield, Figure 4 shows the difference in yield of two varieties from different seed companies with exactly the same GM traits (Yield Guard triple Insect Resistance and Roundup Ready 2 herbicide tolerance). The Nutech variety had the best average yield in the district, but the Cornelius variety came forty sixth out of 52 varieties. The yield difference was 15.9%, which shows that background genetics in each variety counted more than the GM traits.



The performance trials do not attempt to explain these variations, but they clearly indicate that the prevailing environmental stresses and the impact they have on the plants is more important than the presence of GM traits. Again this illustrates that yield is the product of how the whole crop responds to differing external stresses such as low rainfall, high wind, fungal disease or insect pests.

The Iowa performance trials for maize show that SmartStax maize varieties did not yield as well as conventional or other GM varieties in the environments where they were tested. Whether this effect was due to yield drag (caused by the additional GM traits requiring photosynthetic energy which) or yield lag (the impact of background genetics of the parent plants which were genetically modified and crossed to produce the hybrids) is not known. Both may be playing a part. External factors had a noticeable impact on the performance of individual varieties.

Conclusion

The insertion of GM traits in corn alone cannot guarantee higher yields. The performance of crops comes from how well they are adapted to local conditions – and that is a product of all the genes in the plants and their relationship with the prevailing environmental conditions, which vary from season to season and within seasons.

C. Michigan State University soy trials 2010

(see www.css.msu.edu/varietytrials/soybean/2010%20pdf/2010%20Performance%20Report-final.pdf)

Michigan State University carried out variety trails on soybeans along similar lines to those reported above for maize in Iowa.

RR crops' weed control was with Roundup Ultra. In conventional and GM Liberty Link varieties (LL) varieties, weed control was with standard herbicides (with some minor variations the same for each plot). It is assumed that weed competition was not a major issue. One test centre had a severe drought during the growing season, and hence all varieties performed badly in comparison to other sites. Another also had low rainfall, while another received irrigation and temperatures were high throughout the trials creating pretty well optimum conditions for growing.

Table 1 2010 soybean trials summary

Region	Variety type	Mean yield bushels/acre	Max	Min	CV	LSD % (0.05)
Central	Conventional	45.1	50.7	38.8	11.3	3.0
Southern	Conventional	51.3	57.3	39.1	10.9	3.3
Central	RR (early)	48.6	51.3	44.7	11.2	3.2
Central	RR (late)	49.3	53.4	44.7	10.1	2.9
Southern	RR (early)	57.8	62.8	53.6	9.9	3.3
Southern	RR (late)	57.6	61.9	54.4	10.2	3.4
Central and Southern	LL	53.3	58.6	49.6	9.4	2.4

The data (Table 1) indicate that for central area RR varieties average yield is 8.5 % more than conventional. In the southern region the RR increase is around 12.5%. No information about the background genetics of the varieties tested is given, so it is impossible to say if this results from the GM trait and weed control or from the background genetics of each variety. As indicated above weed levels were not mentioned in the report on the trials.

However GM LL variety trials deployed the same herbicides as the conventional and not Liberty (glufosinate ammonium which the GM trait provided tolerance). The mean for LL trials was 53.3 bushels/acre, compared to 45.1 and 51.3 bushels/acre for conventional (an increase of 10.5% taking a mean for the conventional varieties). At the site with the best conditions LL also outperformed the conventional (77.0 bushels/acre against 72.0 bushels/acre), RR (early and late) yielded more than both (80.0 and 83.9 respectively). The LL/conventional comparison suggests that the background genetics in the latter may be inferior in the conditions prevailing and this could explain the yield differences. No information about the genetics the conventional varieties or when they were first bred was given.

The RR varieties may also have superior genetics for the conditions in Iowa, but unless information on parentage of the varieties is forthcoming no firm conclusions can be drawn.

Table 2 Soybean yield ranges

Region	Variety type	Range of mean yields between sites bushels/acre	% difference min and max	Max range of mean yields within one variety between sites bushels/acre	% difference min and max
Central	Conventional	28.1-55.0	95.8%	15.3-54.0	252.9%
Southern	Conventional	42.2-72.0	70.6%	24.4-52.3	114.3%
Central	RR(early)	34.0-58.6	72.3%	29.9-64.3	115.1%
Central	RR(late)	31.5-59.8	89.8%	24.4-59.4	143.4%
Southern	RR(early)	48.0-80.6	67.9%	41.3-83.0	101.0%
Southern	RR (late)	46.3-83.9	80.9%	42.9-93.8	118.6%
All	LL	28.7-58.8	104.9%	29.8-85.9	188.3%

Table 2 shows how yield varied hugely between sites for all varieties (GM or conventional) and within varieties. The differences are larger within individual varieties (GM or conventional) than they were between conventional and GM. This clearly illustrates how yields were strongly influenced by the prevailing conditions at each site (soil quality, temperature, rainfall, disease/pest presence etc) and how the whole genetic make-up responds to these external stimuli.

Summing Up
Without detailed knowledge of the background genetics and previous performance of parent varieties it is not possible to conclude whether the yield differences recorded are due to the respective weed control regimes facilitated by the RR trait or the underlying genetics of the varieties, all of which would have arisen from conventional breeding programmes. Genetic modification was only used to insert the RR and LL traits, which would only impact on yield if heavy weed competition was a factor in the trial. The trial report details weed control methods used in all plots and makes no reference to different levels of weed infestation that might have impacted on the results. The very large differences between different sites for the same varieties compared with those between varieties suggests that the biggest factor dictating yield was how each individual genome coped with the different environmental conditions.

The importance of the socio-economic and cultural influences on crop performance

It cannot be assumed that GM seeds will automatically benefit all farmers. Poorer farmers who have no access to other crop inputs, such as fertilisers, or rely on rain rather than irrigation for water have been found to not gained from the use of GM varieties. Whether or not GM insect resistant cotton (Bt) cotton was a pro-poor technology were reviewed in detail (Glover 2009[20]), which concluded:

> *"Those assumptions have involved the radical simplification of the complex agronomic and livelihood contexts into which GM crops have been inserted. They have thus undermined the usefulness and relevance of the information which has been presented to both farmers and policy makers."*

Mixed variety planting

As indicated above the environmental conditions in which a crop is growing can change enormously during one growing season, for example, from being water-stressed to water-logged, or from being pest free to being heavily infested in a matter of days. Modern arable farming is mainly based on growing single varieties (monocultures) over considerable areas with minimal rotation of different crops, so the genetic base of the system is very narrow compared with plants of the same species growing in a natural ecosystem. Therefore the crops may not be that adaptable to changing conditions, and yields will fall well below their intrinsic yield potential.

At the time of sowing farmers are not able to second guess what conditions will prevail as the crops germinate, flowers, sets seed or ripens. For many decades plant breeding researchers have been developing arable systems based on mixed variety seed lots (evolutionary breeding), which seeks to broaden the gene pool in the crop so that it is better able to cope with the environmental stresses it may experience between sowing and harvest. For instance the mixture of varieties may include strains that cope well with dry conditions and wetter conditions, so that in differing weather conditions one or more varieties would flourish and yield well by occupying the space created by less well-adapted varieties growing less well.

The technique has been applied in several different crops with excellent results. In cereals UK researchers have developed populations adapted for low input farming systems[21]. Evolutionary breeding in dried bean populations produced a 2.5% yield increase per generation compared with the average of parental lines[22]. In China[23] mixed variety planting by thousands of rice farmers reduced the levels of fungal diseases by preventing common pathogens becoming established.

Marker Assisted Selection

Marker assisted selection (MAS) uses modern molecular biology to identify specific desirable genetic traits in potential parental plants before any cross fertilisation takes place. This enables traditional plant breeders to select parents for traits, such as disease resistance, and then check the offspring of crosses to ensure that the desirable trait has been inherited. This process has the potential to speed up conventional breeding techniques and to get new varieties to farmers much more quickly than GM technology and much more cheaply because no risk assessment is required to gain regulatory approval.

MAS is a relatively new technology that depends on having well equipped facilities to scan plant genomes for desired traits and associate these with a marker sequences of DNA. The techniques are not perfected yet[24], but there already been some significant new crop varieties developed using MAS, for example:

- A project to introduce resistance for downy mildew into pearl millet in India took just three years to develop new varieties[25].
- A project to develop drought tolerant rice in India and Nepal[26].
- Good progress is also being made in the publicly funded MAS wheat project in the US[27], which has mainly focused on disease resistance.

The technical ability to ensure that a host of desirable traits, such as disease resistance, can be bred into commercial varieties is growing, but there is a long way to go before pyramiding (stacking) traits in single variety is perfected using MAS.

Although MAS shows great promise in improving crop varieties, just as with the GM approach it will not produce varieties that are adapted to every stress that nature can produce, so crops will remain vulnerable to ever changing conditions in the field. There is still much research and development to be carried out. In addition there are still questions to be resolved regarding the control of the technology by seed corporations and whether it will be made available to all plant breeders to use. Many of the techniques may be patented by the companies that developed them, so may not be available to poorer plant breeding stations or individual farmers who cannot afford to enter expensive licensing agreements. This illustrates how patenting can impede the full use of the world's crop genetic resources.

Intercropping

Intercropping is the practice of growing one or more crops in close proximity, for instance maize and legumes[28], and research has show that it can be more productive than single crop system (Land Equivalent Ratio[2] (LER). It is widely practiced in the Global South[29]. Research to develop these techniques is underway and there are promising results particularly for smaller farmers:

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[2] LAND EQUIVALENT RATIO (LER): the ratio of the area under sole cropping to the area under intercropping needed to give equal amounts of yield at the same management level. It is the sum of the fractions of the intercropped yields divided by the sole-crop yields.

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> *"Maize-cowpea intercropping increases the efficiency of land utilization (higher LER) and has potential to reduce the weeding burden of smallholder farmers-recommended in low input smallholder farming[30]."*

Field trials are also showing that LERs and incomes can vary depending on the patterns of intercropping adopted in maize/soya beans in Zimbabwe[31].

As with mixed variety planting intercropping brings agroecosystems closer to natural ecosystems, which are much better able to withstand environmental stresses than monocultures reliant on inputs rather than genetic resources and resilience.

Agroecological farming

> "*The use of ecological concepts and principles to study, design, and manage agricultural systems. The five main principles being: recycling of nutrients, building soil organic matter; minimizing losses from the system; maximizing biodiversity and genetic diversity; and enhance biological interactions[32].*"

Agroecological techniques aim to creat the best conditions for crops to grow while protecting and enhancing biodiversity and natural resources, such as water and soil quality. Crop and varietal diversity and crop rotation are vital to prevent diseases, weeds and pests becoming major problems. Conventionally bred disease resistant varieties can form part of an overall integrated approach to disease and pest management to avoid the use of pesticides.

Techniques such a multi-varietal planting, MAS and intercropping could play an important part in building a resilient agricultural system that can produce food in a changing climate while protecting ecosystems, biodiversity and natural resources. To make these systems viable farmers and growers must also receive a sustainable income for their work, so the development of agroecological farming must go hand in glove with reforms in market structure, trade and subsidies.

Conclusion

Yield of any crop in any year is a product of the interaction of its genome with the surrounding environment, which can change greatly during the growing season. A variety could perform well in one year but badly the next, even on the same site, depending on how well its genome is adapt to the conditions it faces.

Diverse crops and varieties grown using agroecological techniques are increasingly being seen as the best way to produce reliable yields while coping with climate change and environmental degradation brought about by decades of intensive monocultures. Development of seeds lots using evolutionary breeding techniques will produce crops better adapted than monocultures to cope with changing conditions climate change may produce in the future.

There is no evidence from current GM crops that the technology will produce the yield increases some say are required. Herbicide tolerant and insect resistant GM crops are not designed to increase the intrinsic yield of the crop but to help prevent losses due to weed and pest pressure. Herbicide resistance in weeds can undermine the ability of GM HT crops to prevent losses due to uncontrolled weed competition and herbicide use and costs may have to increase to deal with resistant weeds. Similar processes also occur in GM insect resistant plants.

GM crops developed to increase the intrinsic yield of crops, such as altered photosynthetic pathways or nitrogen fixing, may not be developed at all due to the complexity of the genetic changes involved.

It cannot be assumed that increased yields will automatically arise due to the presence of GM traits, as the results of three US university variety trails show. Valid comparisons can only be made between GM and conventional crops if the GM variety is directly compared with its isogenic equivalent. Results from trials which do not take into account the different genetic backgrounds in the GM and non-GM comparators should not be used without acknowledging that the variation in yields may be due to differences in genetic backgrounds.

The economic standing of farmers using different varieties may also influence how well crops perform and it should not be assumed that poorer farmers will benefit automatically from growing GM seeds if they still cannot afford fertilisers or do not have access to irrigation and have to pay extra for GM seeds.

Annexes

Annex 1 SmartStax variety performance Iowa State University trials 2010

Company/Brand	**Variety/entry**	**District**	**Relative maturity in days**	**Yield as % of district average**	**Yield in bushels/ acre**
Mycogen	2P486	NW	<104	95%	166.3
Mycogen	2J597	NW	104-110	100%	177.6
Renk	RK764SSTX	NW	104-110	91%	160.7
Cornelius	C53SSTX	NW	104-110	91%	160.5
Epley	E2472SS	NW	104-110	90%	159.3
Mycogen	2P486	NE	<104	98%	170.3
Renk	RK619SSTX	NE	<104	96%	167.9
Mycogen	2K594	NE	104-110	102%	186.8
Mycogen	2J597	NE	104-110	101%	184.0
Cornelius	C536SS	NE	104-110	94%	171.2
Renk	RK764SSTX	NE	104-110	90%	164.1
Epley	E2472SS	NE	104-110	89%	163.2
Mycogen	2D692	Central West	104-110	101%	190.9
Epley	E2472SS	Central West	104-110	88%	166.8
Cornelius	C536SS	Central West	104-110	88%	166.3
Mycogen	2D692	Central East	104-110	99%	180.6
Epley	E2472SS	Central east	104-110	93%	168.7
Renk	RK764SSTX	Central east	104-110	92%	168.3
Cornelius	C536SS	Central east	104-110	92%	168.2
Mycogen	2D692	SW	109-112	97%	183.5
Epley	E2472SS	SW	109-112	86%	163.3
Micogen	2T784	SW	>112	99%	167.0
Micogen	X21771	SW	>112	94%	158.7
Micogen	X21771	SE	>112	96%	135.8
SmartStax average				**94.25%**	**168.7**

Annex 2 Non-GM hybrids performance Iowa State University trials 2010

Company/Brand	Variety/entry	District	Relative maturity in days	Yield as % of district average	Yield in bushels/ acre
Epley	E1311	NW	<104	97%	169.4
Prairie	2730	NW	<104	96%	166.3
Prairie	590	NW	<104	94%	163.4
Cornelius	C462	NW	104-110	103%	182.4
Rainbow	X1079	NW	104-110	103%	182.2
Epley	E1471	NW	104-110	102%	181.0
Prairie	4760	NW	104-110	101%	178.4
Prairie	5879	NW	104-110	99%	175.6
Prairie	3074	NW	104-110	96%	169.9
Titan Pro	1059	NW	104-110	95%	168.6
Viking	40-09N	NW	104-110	94%	165.8
Epley	E1170	NE	<104	104%	182.1
Viking	60-01N	NE	<104	101%	176.0
Prairie	579	NE	<104	100%	174.2
Prairie	2730	NE	<104	97%	169.1
Epley	1311	NE	<104	95%	165.7
Epley	E1471	NE	104-110	103%	187.7
Titan Pro	1098	NE	104-110	102%	186.4
Prairie	5879	NE	104-110	101%	183.9
Cornelius	C462	NE	104-110	100%	181.8
Titan Pro	1059	NE	104-110	99%	180.3
Prairie	4368	NE	104-110	98%	179.0
Viking	40-07N	NE	104-110	97%	177.4
Cornelius	C591	Central west	104-110	110%	209.0
Prairie	4760	Central west	104-110	107%	202.4
Rainbow	X1079	Central west	104-110	103%	196.2
Epley	E1471	Central west	104-110	98%	186.2
Prairie	3074	Central west	104-110	93%	175.9
Titan Pro	1059	Central west	104-110	91%	173.7
Titan Pro	1149	Central west	109-114	107%	194.3
Prairie	7820	Central west	109-114	105%	191.0
Rainbow	3157	Central west	109-114	96%	174.8
Prairie	5879	Central east	104-110	101%	184.2
Rainbow	X1079	Central east	104-110	99%	179.7
Prairie	4368	Central east	104-110	98%	179.2
Titan Pro	1059	Central east	104-110	98%	177.8
Prairie	5820	Central east	104-110	96%	174.4
Prairie	7820	Central east	109-114	106%	202.4
Master choice	MC-534	Central east	109-144	96%	184.1
Rainbow	3157	SW	>112	99%	166.7
Prairie	7820	SE	109-112	110%	176.1
Cornelius	C591	SE	109-112	104%	167.2
Rainbow	X1079	SE	109-112	101%	161.6
Prairie	8229	SE	>112	100%	141.4
Titan Pro	1149	SE	>112	94%	133.8
Rainbow	3157	SE	>112	94%	133.0
Non-GM average				**99.6%**	**176.3**

Notes

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