Post Market Monitoring of GM Herbicide-Tolerant Crops

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Determination of Measurement End Points for crop monitoring

- Endpoint must be valid indicator of impact
- Taxonomic resolution must be appropriate
- Protocols should have appropriate temporal and spatial properties
- Statistical power should be appropriate to detect changes
- The statistical and biological validity should not be compromised by logistic and/or financial pressures

What should post monitoring of GMHT crops be looking at?

- Adverse effects on plants esp. weeds?
- Adverse effects on associated wildlife?
- Adverse effects on birds?
- Adverse effects on biodiversity?
- Escapes to non-agricultural environments?
- Gene flow to non GM crops or related species?
- Herbicide residues in local waterways?
- Development of resistance to associated herbicides?

Who should pay for it?

- The manufacturer's who will just put the cost on the product and seed?
- The farmer?
- The government's of Europe i.e. the taxpayer?
- The green lobby?

Is weed control absolutely necessary?

Sugar beet - yes

maize - yes

However, does it need to be perfect?
Like this? Or will this do?

Weed control affects the environment – however it is achieved

**So why is there so much focus
on GMHT crops?**

**All new agricultural practices
(and probably existing practices
too) should be assessed in the
same way**

GMHT – costs & benefits

- *Possible benefits*

- reduced use of herbicides
- use of less persistent herbicides
- can apply sprays later
- less need for insurance sprays
- greater potential to use no-till cultivations

- *Possible harm*

- greater efficiency of weed control
- will be used to clean up weedier fields
- can have effects on biodiversity, especially invertebrates & birds
- can further limit ecosystem services

It was for these reasons that the UK
government set up the Farm Scale
Evaluations in 1999
to determine the impact of GM crops on
the environment –
pre-marketing!

These approaches, or some of them,
could however also be considered for
post market monitoring

The Farm Scale Evaluations

- The null hypothesis was that there is no difference between the management of GMHT varieties and that of comparable conventional varieties, in their effect on the abundance and diversity of arable plants and invertebrates.
- Focus on wildlife – not food safety or gene flow

“This research will not only address GM crops. This is an extremely important opportunity to gain a more detailed understanding of the effects of agricultural management on farmland wildlife generally”

Michael Meacher, Minister for the Environment 1999

Treatments

- Non GM variety + Conventional herbicide programme
- GMHT variety + broad spectrum herbicide to which it was tolerant
 - For beet – glyphosate (Roundup Biactive)
 - For maize and spring and winter rape
 - glufosinate ammonium (Liberty)

Design considerations

- Halved-fields
- Conventional herbicides should be applied according to normal practice
- GMHT management should give cost-effective weed control
- Power (replication) – aimed for 80% chance to detect x 1.5-fold effect – for all three crops this meant 60-70 replicates
- Sites – should be representative of where the crops are grown in UK
- Farms – should aim to include relatively large proportion of less-intensively managed farms (although not many volunteered)

Sampling within half-fields

9 margin sample areas

Locations of trial fields in the FSE

Beet (66)

Maize(68)

Spring oilseed rape (67)

Winter oilseed rape (65)

Trials were done over 3 years

Numbers in brackets were the number of fields tested

Shaded areas are where the commercial crops are grown

What we did

- In total we carried out 14 protocols
- We counted: 700,000 plants
17,000 bees
13,000 butterflies
- We trapped: 500,000 seeds
1.5 million invertebrates
- We made >4000 visits to fields
analysed >7000 datasets

Be impressed, be very impressed- Joe Perry

What it cost

£6 m* = €9 m

So be warned!

*at 2002 prices

FSE Key Results

Herbicide sprays

Crop	Treatment	No of sprays	Number of AI's*	Quantity of AI g/ha
Sugar beet	Conventional	3.7	8.1	2551
	GM	1.7	2.0	1637
Fodder beet	Conventional	3.4	7.0	2495
	GM	1.5	1.8	1484
Maize	Conventional	1.3	2.2	1684
	GM	1.2	1.3	965
Spring oilseed rape	Conventional	1.9	2.2	1376
	GM	1.7	1.7	1334
Winter oilseed rape	Conventional	2.2	2.9	1690
	GM	1.9	1.9	1588

Significantly greater than GM

Active ingredients applied to sugar beet

Conventional herbicides

Glyphosate

Density of broad-leaved weeds: Beet

Significance *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$

NS = no significant difference

Density of broad-leaved weeds: Maize

Significance *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$;
NS = no significant difference

Density of broad-leaved weeds: Spring rape

Significance ** $p < 0.01$, * $p < 0.05$

NS = no significant difference

Density of all weeds: winter oilseed rape

Significance *** $p < 0.001$, * $p < 0.05$; NS = no significant difference

Density of weeds: winter oilseed rape dicots and monocots

Significance *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$; NS = no significant difference

Biomass of weeds at harvest

Significantly greater: *** p < 0.001, * p < 0.05; NS = no significant difference

Weed seed production: measuring seed rain

Weed seed production

Significance *** $p < 0.001$; NS = no significant difference

Invertebrate survey methods

Pitfall traps

Vortis suction sampling

Gastropod refuge traps

Bee / butterfly transects

Groups studied

Rove beetles

Springtails

Ground beetles

Bees

True bugs

Spiders

butterflies

Slugs and snails

Invertebrates on soil surface (pitfall traps): over whole season

Invertebrate group	Beet	Maize	Spring rape	Winter rape
Carabids	No effect*	No effect	No effect	No effect
Staphylinids	No effect	No effect	No effect	No effect
Spiders	No effect*	No effect*	No effect*	No effect*
Springtails	No effect*	No effect*	No effect*	More in GMHT
Slugs	No effect	No effect	No effect*	No effect

* Some significant effects on some occasions with some species or families

Pests and natural enemies on crop plants over whole season

Pest	Beet	Maize	Spring rape
Aphids	No effect	No effect	No effect
Thrips	-	No effect	-
Pollen beetles	-	-	No effect
Predators	No effect	No effect*	No effect
Parasitoids	No effect*	No effect	No effect

* Some significant effects on some occasions

Invertebrates in Vortis samples over whole season

Group	Beet	Maize	Spring rape	Winter rape
Spiders	No effect	No effect	No effect	No effect
Springtails	No effect	More in GMHT	No effect	No effect
Ground beetles	No effect	No effect	No effect	No effect
True bugs	More in conv	No effect	No effect	No effect

Bees in crops

* significantly less at $p < 0.05$; NS = not significant

Significant effects in beet caused by presence of thistles

Butterflies in crops

** significantly less at $P < 0.01$; NS= no significant difference

Comparison of crops: Density of weeds just pre-harvest

Heard et al, 2003: *Phil. Trans. R. Soc. Lond. B*: **358**, 1819-1832
Bohan et al 2005: *Proc. R. Soc. Lond. B*: **272**, 463-474

Comparison of crops: Total seed rain - whole season

Heard et al, 2003: *Phil. Trans. R. Soc. Lond. B*: **358**, 1819-1832
Bohan et al 2005: *Proc. R. Soc. Lond. B*: **272**, 463-474

Comparison of crops: Invertebrates in pitfall traps- whole season

Brooks et al, 2003: *Phil. Trans. R. Soc. Lond. B*: **358**, 1847-1862

Bohan et al, 2005: *Proc. R. Soc. Lond. B*: **272**, 463-474

Comparison of crops: Invertebrates in Vortis samples - whole season

Haughton et al, 2003: *Phil. Trans. R. Soc. Lond. B*: **358**, 1863-1877

Bohan et al, 2005: *Proc. R. Soc. Lond. B*: **272**, 463-474

Conclusions

- Fewer herbicides were used in the GMHT halves of three of the four crops
- Herbicide treatments produced fewer weeds, weed biomass and seeds in GMHT beet and spring and winter rape, but more in maize
- These differences were due to the efficiency of control of the various herbicide regimes, NOT GMHT PER SE

Conclusions: consequences

- No overall effects on ground beetles, rove beetles, spiders, springtails, slugs, pests, but some effects on individual species on some occasions consistent with diet
- Fewer butterflies in GMHT beet and rape, but differences larger between crops
- Fewer bees in GMHT beet

Key References

- For beet, maize and spring rape, Special issue of :
 - Philosophical Transactions of the Royal Society Volume 358; No.1439, 1773 – 1913.
- Bohan et al 2005: (winter oilseed rape only)
 - Proceedings of the Royal Society B, **272**, 463-474.
- Dewar et al, 2005 (for summary)
 - Outlooks on Pest Management, **16(4)**, 164-173

Outcome

- The UK government banned the growing of GMHT oilseed rape and beet, but approved the growing of GMHT maize so long as it was grown like those in the FSE
- Bayer (formerly Aventis) withdrew the variety of GMHT maize that was used in the FSE, so no GMHT crops have since been grown in the UK

Cost of protocols in the FSE*

Protocol	Cost/site	Protocol	Cost/site
Field layout	£357	Seed rain	£2552
Seedbank	£2297	Bees & butterflies	£418
Follow-up seedbank	£4548	Insects on crops	£344
Crop assessment	£782	Vortis	£1208
Weeds in fields	£2066	Pitfall traps	£3000
Weeds in margins	£566	Gastropods (f+m)	£713
Follow-up weeds	£601	TOTAL	£19453

*At 2002 prices; subsample of 113 /266 sites

•From Qi et al (2008) Annals of Applied Biology **152**, 93-101

Effects of GMHT crops on birds 1

- In beet and spring oilseed rape, rain of weed seeds important in the diets of 16 bird species was significantly reduced in GMHT compared to conventional halves; for no species did it increase.
- In winter oilseed rape, rain of weed seeds important in the diets of 10 species was significantly reduced in GMHT halves; for only one species did it increase significantly.
- By contrast, in maize, rain of weed seeds important in the diets of seven species was significantly greater in GMHT halves; for no species was it reduced.

Gibbons et al 2006, *Proc. R. Soc. B* 2006 **273**, 1921-1928

Predicted effects of GMHT crops on Farmland Bird Index (FBI)*

FBI in 2001	Predicted FBI in 2020		
	Current land management continued	GMHT crops introduced in 2005	ELS introduced in 2005
0.54	0.42	0.40	0.47

ELS = Entry Level Stewardship agri-environment scheme

* Includes 39 species of farmland birds

Predicted effects of GMHT crops on Farmland Bird Index (FBI)

“...GMHT crops would only have a limited effect on FBI” ...

However, despite employment of agri-environment schemes

“...the FBI will continue to decline driven by detrimental conditions persisting in the cropped area”

Butler et al (2007). Science **315**, 381-384

Gene flow to non GM crops

- Survey conducted by Central Science Laboratory (CSL, now FERA)
- Only oilseed rape and maize crops sampled.
- In maize, gene flow was detected up to 200m from GM source
 - Recommended separation distance = 3 m to comply with <0.9% 'cross pollination' threshold
 - Weekes et al (2007) Transgenic research 16(2), 203-211
- In OSR, a model predicted cross pollination of 0.04% in WOSR, 0.02% in SOSR at 50 m from the source
 - Weekes et al (2005) Transgenic Research 14(5), 749-759

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Development of herbicide-resistant weeds

- There are 18 species now recorded as being resistant to glyphosate
(<http://www.weedscience.org/In.asp>)
- Many are associated with glyphosate usage in GMHT crops
- The solution is to adopt crop rotations and cultivation systems in which weed control is not dependent on only one herbicide

Mitigation measures

- Set-aside headland
- Better margin management
- In crop weed-refugia
- Less intense weed management
- Band-spraying
- Reduced tillage
- Overwintered stubbles

A win:win vision for agriculture & environment

The End