The impact of the EU regulatory constraint of transgenic crops on farm income

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World population and the need for nutritious food continue to grow. For 14 years farmers from a range of countries across the globe have been accessing transgenic technologies either to reduce crop production costs, increase yield and/or to exploit a range of rotational benefits. In 2009 134 Mha of transgenic crops was grown. The arable area of the EU 27 is approximately 102 Mha; however, only about 0.1 Mha of transgenic crops, mainly maize in Spain, is grown in the EU. This is in part due to limited approvals before the establishment of a moratorium on the cultivation of transgenic crops. In this paper we estimate the revenue foregone by EU farmers, based on the potential hectarages of IR and HT transgenic crops that have been economically successful elsewhere if they were to be grown in areas of the EU where farmers could expect an overall financial benefit. This benefit would accrue primarily from reduced input costs. We estimate that if the areas of transgenic maize, cotton, soya, oil seed rape and sugar beet were to be grown where there is agronomic need or benefit then farmer margins would increase by between €443 and €929 M/year. It is noted that this margin of revenue foregone is likely to increase if the current level of approval and growth remains low, as new transgenic events come to market and are rapidly taken up by farmers in other parts of the world.

Background and introduction

Although the UN Food and Agriculture Organisation reported that the number of undernourished people had declined significantly between the 1970s and early 1990s they still estimate the number of undernourished people in the world in 2008 at 915 million [1] and this is against a backcloth of world population that is expected to continue to increase until 2050, when the population is expected to stabilise at about 9 bn [2]. Improvements in the productivity of world agriculture are seen by the FAO as essential. Biotechnology, including transgenic crop development, is contributing to alleviation of hunger; however, FAO commented that 'there is still a need to step up investment in agriculture with the dual purpose of stimulating sustainable productivity increases to expand supply and of exploiting the potential of agriculture to contribute to economic development and poverty alleviation'.

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Techniques such as genetic modification and marker-assisted selection have demonstrated unequivocally that crop yields are capable of further enhancement [3]; productivity of transgenic crops commercialised up to 2008 has consistently exceeded that of conventional crops, even though they were not specifically developed for increased yield [4].

Since the first wide-scale planting of transgenic crops the area grown globally has expanded rapidly with about 134 Mha grown in 2009, principally maize, cotton, soya and canola. These are grown mainly in eight countries although the range of nations now growing transgenic crops has expanded to 25 [5]. Brookes *et al.* [6] calculated that world prices of maize, oilseed rape and soyabeans would be respectively 5.8%, 3.8% and 9.6% higher if transgenic crops were not available to farmers. Prices of key derivatives of soya beans or oilseed rape, including feed, would be higher by 4–9%, and there would be related increases in the prices of all close substitutes. These calculations were made by Brookes *et al.* [6] using the FAPRI/CARD International Grains

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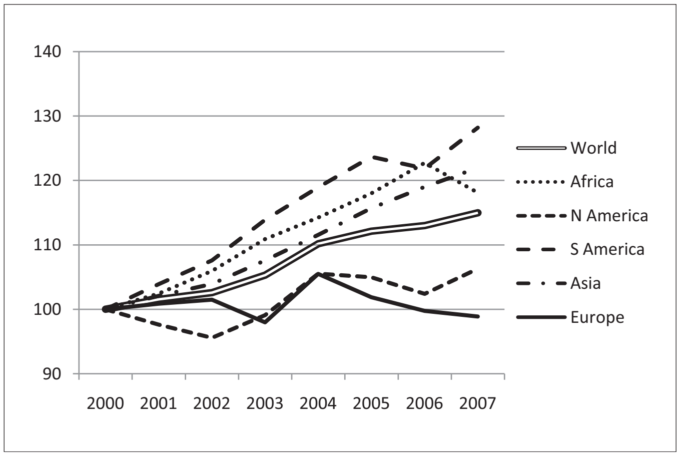

FIGURE 1

Agricultural production trends 2000–2007 (*source*: FAOSTAT 2010).

TABLE 1

EU GMO notifications and final reports (EU GMO Register, 2010)

Crop	Notifications	Final reports
Maize	375	72
Potato	77	4
Cotton	34	18
Rice	20	0
Oilseed rape	18	4
Sugarbeet	16	3
Wheat	9	2
Soyabean	3	0
Pea	3	1
Unallocated	66	0
Total	621	104

Model [7]. It has been suggested [8] that transgenic crops have the potential to contribute to the sustainable development agenda and this is supported by a recent review [9].

Against this backcloth growth of transgenics on the 102 Mha of arable land in the 27 EU states has been and continues to be limited. The European Union (EU) has relative food security, and remains a net exporter of food commodities, but food production, unlike in the rest of the world, is not increasing (Fig. 1). Food security in the EU has been achieved by means of strong performance in the farming sector under the Common Agricultural Policy (CAP); the first objective of the CAP according to Article 39 of the Treaty of Rome in 1957 was 'to increase productivity, by promoting technical progress and ensuring the optimum use of the factors of production, in particular labour'. The CAP was very successful in moving the EU toward self-sufficiency from the 1980s onwards, to the extent that almost permanent surpluses of the major farm commodities became a problem. Some of the surplus was exported, with the help of subsidies [10]. The EU brought in policy measures to try to limit the production of surplus products, and gradually these policies succeeded and surpluses were reduced. Productivity was of secondary concern, and yields have almost ceased to increase. The current CAP [10] has new strategic objectives: 'an agriculture that is competitive on world markets, which respects very strict standards on environment, food safety, and animal welfare, within a framework of a sustainable and dynamic rural economy.' New agricultural policy objectives have arisen in the EU concerning sustainability, and there are a range of measures and frameworks in place to move toward more sustainable development trajectories [11].

In relation to transgenic crops, and mainly related to concerns about food safety, the European Union established a legal framework regulating genetically modified (GM) food and feed in the EU. The extent and complexity of regulations concerning cultivation and use of these crops is such that only three events, maize MON810, maize HT T25 and potato EH92-527-1 (BASF Amflora), have been approved for cultivation, and only a few other events have been approved for import. These are listed in the GMO register, a database maintained on behalf of the EU [12]. The crop with the largest number of events approved for import is maize (16 events at the start of 2010).

The EU regulations [13] have severely limited the cultivation of transgenic crops, although before EU entry Romanian farmers cultivated biotech herbicide-tolerant soyabeans on about 140 kha compared with 60 kha of conventional crop [14]. In Spain the cultivation of Bt maize, although limited, has steadily increased, reaching 80 kha in 2008 [4].

A long queue of applications for the introduction of other events awaits the attention of the European Food Safety Authority (EFSA); an EFSA Opinion is mandatory before formal approval for either import or cultivation can be issued by the European Commission. Prior notification must be given to the competent national authority of the planned placing on the market of a GMO, which must be sent to the competent authorities of the other Member States and to the Commission, and which the Commission must immediately make available to the public. The Final Report is an assessment of food safety prepared by EFSA, after which a decision is eventually made by the Commission, unless an earlier decision can be arrived at by qualified majority vote in a standing committee or in the Council. A summary of the numbers of pending applications and final reports at the end of 2009 is shown in Table 1.

In this paper, on a crop by crop basis, we estimate the areas of the main cultivatable transgenic crops that could be usefully grown for agronomic purposes (if permitted) and use internationally derived yield and input data to make estimates of the current economic consequences of restricting approval, release and growth of transgenic crops across the EU27. We consider potential crops in relation to insect resistance (IR) and herbicide tolerance (HT), making estimates related to both before discussing estimates of total revenue foregone and the implications for on-going limited use of these technologies in the EU. Smale *et al.* [15] describe this approach as 'partial budgeting', being based on marginal changes in variable costs and benefits per hectare. They contrast this method with 'damage abatement' modelling although such an approach is difficult to implement as there is, as yet, little documented evidence of the wider economic costs or benefits of transgenic crops, such as consumer price impacts and returns to investment in biotechnology via intellectual property rights. It should be noted that such wider consequences will have an impact on adoption rates but these have not been modelled in this

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TABLE 2

Transgenic maize cultivation in EU (GMO-Compass, 2010)

Country	GM maize (ha)				
	2005	2006	2007	2008	2009
Spain	53,225	53,667	75,148	79,269	76,057
France	492	5000	21,147	[Ban]	[Ban]
Czech Rep	150	1290	5000	8380	6480
Portugal	750	1250	4500	4851	5094
Germany	342	947	2685	3171	[Ban]
Slovakia	0	30	900	1900	875
Romania	0	0	350	7416	3344
Poland	0	100	320	3000	3000
Total	54,959	62,284	110,050	107,987	94,850

research. Further there could be the opportunity for a revival of EU capability in crop biotechnology, which would strengthen research and lead to the introduction of transgenic varieties better suited to the EU farming environment.

Maize

Overview

IR transgenic maize is currently grown on a limited area in the EU. As shown in Table 1, maize has been the subject of more than half the GMO notifications submitted to EU Joint Research Centre (JRC). Internationally, IR Bacillus thuringiensis (Bt) Maize has been adopted very widely as a method of managing pest pressure, and the success of single trait modifications has been followed by stacking of traits, so that Bt/Bt, Bt/HT and Bt/Bt/HT now offer farmers worldwide a range of strategies to counter pest and weed pressures. It is estimated that in 2009 41.7 Mha of IR maize was grown worldwide [5]. In North America the European Corn Borer (ECB) has been a major pest affecting maize (corn) crops for over 60 years [16]. Initial control with DDT became unacceptable, and organophosphates and pyrethroids were subsequently used. Plant breeders tried to develop strains resistant to ECB, with mixed success. Koziel *et al.* [18] were eventually able to report successful trials with transgenic maize plants expressing insecticidal protein derived from Bt. Western Corn Rootworm (*Diabrotica virgifera virgifera*) (WCR) another major pest affecting maize, can also be controlled by expression of proteins from Bt. WCR has been spreading through Europe since 1992 [19,20].

About 60 Mt of conventional grain maize is grown annually in the EU on 8.5 Mha [21]. In 1998 two transgenic maize events, IR MON810 and HT T25, were approved for cultivation in EU, and both approvals remain valid as transgenic crops that were lawfully placed on the EU market before the entry into force of Regulation 1829/2003 on transgenic food and feed on 18 April 2004. MON810 is being grown in six EU countries at the time of writing (Czech Republic, Poland, Portugal, Romania, Slovakia and Spain) and in previous years was grown in two other EU countries (France and Germany) until being banned. T25, although approved, is not represented in the market [12]. In June 2009 EFSA endorsed the re-authorisation of MON810 for cultivation, despite strong opposition from several member states. Following EFSA's endorsement, an announcement is awaited from the EU; no decision had been announced up to October 2010, but cultivation is still permitted by the European Commission pending an announcement.

Wherever farmers have been allowed to cultivate MON810 maize within Europe to combat pressure from stem borer pests, economic benefits have been achieved [17,20,22,23]. As shown in Table 2, adoption has generally been rapid and, where permitted, sustained. This economic advantage of IR transgenic crops is only relevant in regions where pest pressure is both severe and recurrent. Various climatic and other factors cause insect populations to fluctuate meaning that the economic advantage can also fluctuate, although this can be difficult to predict at the time of planting. WCR arrived in Europe, in Serbia, in 1992, and spread rapidly with serious economic impact on European maize crops [16]. Containment measures have been partially successful, and the European and Mediterranean Plant Protection Organisation monitors the annual changes in distribution [24].

Further spread of both ECB and WCR is possible, and may be linked to climatic change, the consequences of which are difficult to predict [25]. However it has been noted that the rate of spread of pest populations is to some extent temperature dependent [26].

Benefit available to EU

In the maize growing regions of Spain that are affected by ECB or WCR pests, the adoption of transgenic IR maize has consistently improved yield/ha [20,27]. The estimated proportion of maize-growing area that was affected in 2007, by country, is summarised in Table 3; the pest-affected areas continue to spread northwards.

Several studies have reported that the reduction of pest damage after the introduction of Bt maize in place of conventional maize results in enhanced yield. Huesing and English [28] commented that the use of this technology revealed the true extent of the economic damage caused by stalk-borer feeding insects, such as ECB, which cause an estimated 4.5% reduction in maize yields in the United States and up to 10% elsewhere. Before the introduction of Bt maize, only limited efforts were made to control stalk-borer damage. In addition to damage caused by ECB, there is a growing threat of damage from the rapid spread of the WCR which could also be reduced following adoption of Bt maize [29,30].

Demont [17] reported that 5.7% of maize grown in Spain 1998–2003 was IR transgenic maize, delivering a net benefit of 70 €/ha. For worldwide transgenic crops, Demont estimated that about

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TABLE 3

Maize growing regions affected by pests (areas from Eurostat, average 2004–2008; proportions from Brookes [27])

	kha	% area affected by pests in 2007
Bulgaria	372	10–15
Czech Republic	286	15–30
Germany	1759	17–28
Greece	253	5–24
Spain	491	12–16
France	3001	10–25
Italy	1395	30–80
Hungary	1279	5–10
Austria	247	50–70
Poland	664	20–50
Portugal	222	6–10
Romania	2688	18–32
Slovakia	240	20–33

TABLE 4

Benefits that might accrue to farmers adopting transgenic IR maize

	Mha	Gross margin change (€/ha)	€M[a]	
			From	To
Bulgaria	0.37	97[b]	3.6	5.4
Czech Republic	0.29	107	4.6	9.2
Germany	1.76	86	25.7	42.4
Greece	0.25	97[b]	1.2	5.9
France	3.00	114	34.2	85.5
Italy	1.39	97[b]	40.6	108.2
Hungary	1.28	97[b]	6.2	12.4
Austria	0.25	97[b]	12.0	16.8
Poland	0.66	90	11.9	29.9
Portugal	0.22	106	1.4	2.4
Romania	2.69	25	12.1	10.5
Slovakia	0.24	75	3.6	5.9
Total	12.40		157	334

Area data from Eurostat and crop values for conventional maize taken from Brookes [32].

[a] Mha × gross margin change × proportion of area affected shown in Table 3.
[b] Average elsewhere if no data.

two-thirds (61–74%) of benefit accrued 'downstream' in 95% of instances; for crops in Europe, the downstream share was slightly lower, at 60–65%. These estimates are consistent with the economic impact by country estimated by Brookes [27], who gave details of the benefits achieved in different regions of Spain. Brookes [31] estimated net annual average saving on cost of production (from lower insecticide use) over eight growing seasons consistently between €34 and 42/ha, while the net increase in gross margin arising from enhanced yield was between €86 and 108/ha, but only in areas of high insect infestation did the savings on pesticide exceed the seed premium. If a similar net benefit from input savings combined with yield increase were to be achieved over the pest affected areas of the countries other than Spain listed in Table 3, the estimated value to farmers in those countries would be of the order of €157 M–€334 M, as shown in Table 4 (note Table 4 excludes Spain to ensure the estimate relates to new income). This is based on area data from Eurostat and crop values for conventional maize given by Brookes [32]. Data on % areas potentially affected by the pest are derived from Brookes [27,31]. In practice, the net benefit will depend on market prices, and the estimation also assumes that the cost of compliance with existing coexistence regulations in the EU will remain in line with the costs currently borne by farmers growing IR maize in Spain. It is likely that this is an under-estimate as the potential benefits of using Bt to overcome the increasing threat of WCR described in Dillen *et al.* [20] have not been included.

Cotton

Overview

16 Mha of Bt cotton was planted in 2009, almost half of 33 Mha (25 Mt) of world cotton cultivation [5]. Bt cotton has brought major economic advantages [33], with benefits in many countries exceeding $50/ha relative to conventional cotton. Yields are improved by reduction in insect pests, and costs are reduced by requiring fewer insecticide spray treatments. By 2008 [4] transgenic cotton represented 46% of global cotton production. Anderson [34] suggested that lower production costs associated with Bt cotton could reduce the world price of cotton, but estimated that global economic welfare was enhanced by US$700M from its adoption, in addition to net profits accrued to biotechnology firms and seed suppliers.

Although cotton is not a major crop in the EU, both Greece and Spain have significant cotton production. It should be noted that if Turkey joins the EU the importance of cotton will increase markedly as Turkey currently grows 500 kha [21]. In 2005 Greece planted 360 kha of conventional cotton, although following changes in the EU Cotton Regime the area grown fell due to higher production costs, and only 200 kha was expected to be planted in 2010 [35,36]. In addition about 60 kha of conventional cotton is also grown in Spain. No Bt cotton is permitted for cultivation in EU despite vulnerability to damage caused by bollworm *Earias insulana*, a pest found wherever cotton is grown in the world [37].

Benefit available to EU

In the rest of the world, Bt cotton has been a very successful transgenic crop, including in recent years many transgenic varieties with stacked traits. Bennett *et al.* [38] showed that Bt cotton varieties had a significant positive impact on average yields and on the economic performance of cotton growers in India. Qaim [39] presented data on the comparative advantage of Bt over conventional cotton from randomly sampled farms in four Indian states for the years 2002, 2004 and 2006, showing not only consistent advantage between $111 and $152/ha (equivalent to a range of about €80 to 110/ha at €1 = $1.4), with an average of $135/ha but also a decline in target pest population that was also of benefit to conventional cotton growers. James [4] confirmed that adoption in India continued rapidly, with 7.6 Mha of Bt cotton grown in 2008. Karihaloo and Kumar [40] summarised the outcomes of

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numerous peer-reviewed studies of experience with Bt versus conventional cotton in India, and found that net economic benefit ranged from US$71 to more than US$300/ha, equivalent to a range of about €50 to 220/ha. Vitali *et al.* [41] investigated economic incentives for adoption of Bt cotton in West Africa, where pest pressure is severe; they reported yield increases of 20%. There is evidence of yield increases from Bt cotton from various countries, in the range 6–30% [42,43].

Six cotton events had been approved up to 2008 for food and feed applications in EU: HT varieties MON1445 and Liberty Link 25, Bt varieties MON531 and MON15985, and dual-trait varieties MON531xMON1445 and MON15985xMON1445 [4]. Applications have been outstanding since 2003 for cultivation of Bt cotton MON531, and HT cotton MON1445. If the benefits reported by James together with those reported by Qaim for Bt cotton in India are taken as indicative of the likely economic advantage per ha, this is equivalent to not less than €50/ha potential benefit to EU farmers, and possibly as high as €150/ha, even allowing that farmers in less-developed countries initially growing conventional cotton probably operated at lower levels of basic performance. The annual potential benefit of about €80/ha (mid-range for data from elsewhere) to farmers with about 260 kha of cotton in Greece and Spain would be €20.8 M.

Soyabean

Overview

HT soya has been adopted very widely in North and South America as a method of weed control, often leading to changes in rotational and fallowing practice; 77% of the 90 Mha of soybean grown globally in 2009 was transgenic [5]. In 2008, 66 Mha of transgenic soyabeans was planted worldwide, more than half of total cultivation. 18 Mha of transgenic soyabeans was grown in Argentina alone, with 30% of production exported as grain and 68% processed by the oilseed industry within Argentina; 93% of the soybean oil is exported.

Adoption of transgenic HT soyabeans led to rapid increase in yield per hectare in Romania. Yield impacts of over 16% were reported due to improved weed control, especially of 'difficult to control' established weeds like Johnson grass [44]. In a study of soy-based diesel fuel in Argentina, Tomei and Upham [45] noted that the use of a 'technological package', consisting of transgenic seed, no-till and glyphosate, had consolidated an export-focused model of agriculture, based on mechanised, large-scale production. Tomei and Upham reported data showing that yields increased from 2105 kg/ha in 1996 to 2826 kg/ha in 2008. However, in a wide review of the economics of transgenic crops, Qaim [46] found that in terms of the yields achieved, no significant difference between HT and conventional soya is reported in most cases.

Qaim and Traxler [47] reported the economic benefits of transgenic soyabeans grown in Argentina, USA and elsewhere from 1996 to 2001. The results showed that soyabean producers, consumers, and the private sector all benefit from the use of Roundup Ready soyabeans. The increase in total factor productivity was 10% on average for Argentina. Owing to lower overall production costs, this productivity increase was higher than that in USA. Kumudini *et al.* [48] found that transgenic soyabeans consistently maintained their yield advantage, though HT soyabean has not resulted in a major reduction of treatments comparable with the pesticide savings of 60% associated with insect-resistant cotton [49].

Moisture retention was the key advantage of wheat, maize and soyabean rotation recommended for rain-fed cultivation in Argentina [50]. For many years the rotation of conventional soyabean with conventional maize was the preferred strategy for managing root-worm infestation in maize crops in USA, but the pests developed rotation-resistance; this has been part of the incentive for adoption of Bt maize [51].

In a case study of the rapid adoption of HT soyabeans in the USA [52], the convenience of weed control was reported as a key factor in farmers' decision-making. In Europe, by contrast, weed control in cultivation of conventional soya continues to present farmers with serious problems. Vollmann *et al.* [53] conducted a three-year study to investigate the effects of weed pressure on yield and quality of soybean cultivars grown in Austria. They recorded the effects of competition for light, nutrients and water, and quantified the reduced grain yield associated with weed infestation. In two seasons, strong competition from weeds caused a soybean yield reduction of 370 and 560 kg/ha, respectively, compared with mean weed-free yield of about 2500 kg/ha. In a third season a significant yield increase over weed-free controls was observed at relatively low levels of weed pressure which Vollmann *et al.* explained as being non-competition effects of a weak weed ground cover on soybean growth.

Benefit available to EU

In 2005 and 2006, before EU entry in 2007, Romanian farmers cultivated biotech herbicide-tolerant soyabeans on a large scale, on about 140 kha compared with 60 kha of conventional crop [14]. Farmers who used HT soyabeans indicated that this crop was the most profitable arable crop grown in Romania, with gains derived from higher yields and improved quality of seed coupled with lower costs of production [54]. However, no transgenic soya is now permitted for cultivation in the EU. Soyabean event MON4032 was authorised for import in 1998 and has been awaiting authorisation for cultivation since 2006. Events Liberty Link A2704 and MON89788 were authorised for import in 2008.

In 2009 only about 0.5 Mha was planted in the EU with conventional soyabeans, yielding about 1.2 Mt [21], whereas 18 Mt of soyabeans was imported by EU countries in 2007 [55]. The 9 EU countries in which more than 2500 ha is planted with conventional soyabeans are shown in Table 5. Direct yield/ha may not

TABLE 5

Soyabean cultivation in EU (kha) (Eurostat [21])

	2007	2008	2009
Italy	130	108	135
Romania	133	50	49
Croatia	47	36	43
Hungary	33	29	31
France	32	22	44
Austria	20	18	25
Slovakia	8	5	10
Czech Republic	8	4	6
Bosnia-Herz	5	4	4

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TABLE 6

Oilseed rape cultivation in EU (kha) (Eurostat [21])

	2004	2005	2006	2007	2008
EU (27)	4483	4716	5229	6489	–
France	1125	1232	1406	1616	1421
Germany	1283	1344	1429	1548	1371
Poland	538	550	624	797	771
United Kingdom	558	519	500	668	598
Czech Republic	260	267	292	338	357

increase if HT soyabeans are grown in Europe, but input savings have been reported at the equivalent of €30/ha [42,56]. This is a similar value as reported by Marra [42] from farms in North Carolina where profit relative to the conventional crop was $6 to $22/acre (€10 to €38/ha) greater. Assuming these margins across the 0.5 M/ha then this would lead to an estimated benefit of between €5 and €19 M.

Oilseed rape

Overview

Canola was bred from rapeseed, with exceptionally low content of erucic acid; the name was derived from ''Canadian oil, low acid''. The crop was rapidly adopted for its nutritional quality, but weed pressure was found to affect performance, and HT glyphosate-resistant canola was shown to give significant economic benefit [57,58]. HT canola cultivation in 2009 represented about 20% of the 31 Mha of rape cultivation worldwide [5]. About 6 Mha was planted with rape in EU in 2009 [21] yielding about 20 Mt, with strong demand for rape as feedstock for biodiesel.

From a sample of farms in Canada, Marra *et al.* [42] reported profit relative to the conventional crop of up to $24.5/acre, equivalent to €43/ha. Smyth *et al.* [59] analysed results from a survey of canola production in western Canada regarding the performance of transgenic canola in respect of tillage, herbicide use and weed control practices. The survey revealed that the new technology generated Can$1 bn annual net direct and indirect benefits for producers over 2005–2007, partly attributed to lower input costs and partly attributed to better weed control. Smyth *et al.* [59] commented that crop insurance agencies in Western Canada recommend that canola be seeded on a field at most once every four years to minimize risk from insect populations and plant diseases, but producers gain indirect benefit as a result of fewer weeds or easier weed control on fields that had been previously seeded to HT canola. Taking indirect benefits into account, Smyth *et al.* [59] concluded that HT canola provided farmers with the equivalent of Can$65–73/ha (€49–55/ha)[1] in the years 2005–2007.

Canadian growers have remained convinced of the economic benefits, and in every year since 2000 more than 85% of Canadian canola has been transgenic. A small quantity of conventional canola, mainly organic, is grown every year, indicating that coexistence of transgenic with conventional canola is manageable.

Oilseed rape is a major crop in European arable farming, and demand has increased because rape oil is being used as feedstock for biodiesel. The total EU crop areas for 2004–2008, and the crop areas in the five countries with the largest production are shown in Table 6. Lutman *et al.* [60] evaluated HT rape over 4 years in rotations at three sites, in comparison with conventional rape. They achieved similar weed control performance in all plots, but the HT rape required only a single application of glyphosate or glufosinate, whereas the conventional rape required two applications of broad-leaved weed herbicide. Yields in all plots were close to the expected 3.3 t/ha. Lutman *et al.* [60] reported that they had much greater flexibility in the timing of control with the HT crops.

Benefit available to EU

In 2004 EFSA GMO Panel published their opinion that GT73 oilseed rape is as safe as conventional oilseed rape and therefore the placing on the market of GT73 oilseed rape for processing and feed use is unlikely to have an adverse effect on human or animal health or, in the context of its proposed use, on the environment. The scope of the applications for release of GT73 excluded import of viable plant material and cultivation, so there was no requirement for scientific information on environmental safety assessment of accidental release or cultivation. The EFSA GMO Panel concluded in September 2009 that there is no new information provided by the applicant or in the scientific literature that would require changes of its previous scientific opinion on oilseed rape MS8, RF3 and MS8 × RF3, and the Panel reiterated their previous opinions that transgenic oilseed rape MS8, RF3 and MS8 × RF3 is unlikely to have an adverse effect on human and animal health or, in the context of its proposed uses, on the environment. In December 2009, EFSA published a further Opinion on food and feed products produced from oilseed rape GT73, addressing scientific comments raised by Member States, and restated that GT73 is unlikely to have an adverse effect on human and animal health and on the environment, in the context of its proposed uses.

Although transgenic oilseed rape is yet to be approved for field scale cultivation in the European Union (EU), stakeholders are beginning to prepare for the commercial release of transgenic varieties [61]. Policy-makers face difficult choices as to how to deal with potential externalities from cross pollination: oilseed rape pollen can be dispersed over large distances by wind or insects, 'contaminating' non-transgenic rape varieties. On the contrary, farmers can be expected to gain from the new technology, which offers higher gross margins than its conventional counterpart. Farmers may respond to the liability rules regarding cross contamination in several ways, for example, by concentrating transgenic varieties on adjacent plots or by coordinating the spatial pattern of transgenic cropping across different holdings so as to keep cross pollination to a minimum. Breustedt *et al.* [61] explored German farmers' willingness to adopt transgenic oilseed rape via a survey offering a choice of scenarios. Prospective adoption decisions were determined primarily by the difference in gross margin, but also by expected liability from cross pollination and by restricted flexibility in returning to a conventional crop. Under EU legislation, farmers can be held liable for damages arising from cross pollination [62] and Breustedt *et al.* [61] doubted that German arable farming would actually benefit from the approval of herbicide-tolerant rape if the net advantage after input savings and better weed control was less than €100/ha.

Nevertheless a conservative estimate of net benefit of between €30 and 49/ha of introducing transgenic canola to Europe, based

[1] Assuming one Canadian Dollar = 0.75 Euros.

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on the data of Marra *et al.* [42] and Smyth *et al.* [59] from Canada and applied to 6.5 Mha in EU, would indicate a potential annual benefit to EU farmers of between €195 and 318 M.

Sugarbeet

Overview

Sugar beet provides 230 Mt or about one eighth of annual world consumption of refined sugar, the rest coming from sugarcane (1750 Mt) (FAOSTAT 2010). HT sugar beet was recently introduced to help farmers deal with weed pressure, and for a time was rapidly adopted in USA, although cultivation in 2011 may be prevented pending a judicial requirement for further environmental impact assessment. In 2009, 95% of the 485 kha of sugarbeet planted in the United States was devoted to varieties improved through biotechnology [5].

In 2005, 137 Mt of sugar beet was produced from 2.2 Mha in the EU [21]. In that year the European sugar policy underwent reform, involving reduction in the European sugar price over a four year period (sugar producers were partially compensated for the cut by a decoupled direct income payment). Output decreased to 101 Mt in 2008, from 1.46 Mha of cultivation.

Trials were conducted in Spain in 2008 of HT sugar beet H7-1, and a report was submitted by EFSA stating that 'sugar beet varieties with genetic modification H7-1 behave similarly to the conventional sugar beet and it has not observed any negative effect on human or animal health, or on the environment' [63], and similar releases have taken place in Germany, Sweden and Czech Republic without negative effects being observed.

Dillen *et al.* [64] reviewed the global welfare effects of HT sugar beet following commercial adoption of HT sugar beet in the USA in 2008, noting the reduction of EU internal sugar prices following the reform of sugar trading in the EU. The reform had the effect of providing incentives for economic efficiency of sugar producers in Europe. All yield increases were found to enhance global welfare, and predicted benefits would be shared approximately one third each between suppliers, farmers and consumers, in line with impact studies of other transgenic crops [17]. Most countries in EU grow some sugar beet; yields vary depending on climate, and other factors (19 countries each grew more than 9 kha in 2008, Table 7).

TABLE 7

Sugarbeet cultivation in EU, 2008 (kha, Eurostat [21])

Germany	369
France	349
Poland	188
United Kingdom	120
Netherlands	72
Italy	62
Spain	52
Czech Republic	50
Austria	43
Sweden	37
Denmark	36
Croatia	22
Romania	20
Switzerland	20
Greece	14
Finland	14
Slovakia	11
Hungary	10
Lithuania	9

Benefit available to EU

HT sugar beet is expected to be of economic benefit to growers in UK and Europe. May [65] observed that weed control is one of the more expensive inputs to sugar beet production. May calculated that growers of HT sugar beet could expect direct annual savings of £80/ha in agrochemical use, together with other savings, net of higher seed costs, worth a further £74/ha at 2003 prices. Demont *et al.* [66] estimated the likely benefit of HT maize and HT oilseed rape together with HT sugarbeet in a description of modelling of farmer heterogeneity under imperfect information; the potential value of HT sugarbeet was found to be particularly high, and supported the predictions made by May. The assumptions made by May concerning inputs and costs in UK are likely to be broadly similar to those of sugar beet growers elsewhere in the EU. A conservative estimate is that savings from adoption of HT sugar beet are likely to be in the range €50–€150/ha.

Allowance needs to be made for a smaller overall gross margin for EU sugar beet growers following the gradual change in sugar price support system from 2006, but even at €50/ha, the lower end of the range of likely economic benefits, the annual economic benefit for growers in EU over the current 1.46 Mha would be €73 M. If the higher margin of €150/ha is assumed then this figure rises to €219 M.

Discussion

Very few hectares of transgenic crops are currently grown in the EU despite 134 Mha being grown elsewhere in the world (the total arable area of the EU is about 102 Mha, Eurostat [21]). A range of transgenic crops await approval for use in the EU, yet despite clear benefits being demonstrated elsewhere in the world, approval processes in the EU remain slow. Evidence suggests that in many areas yields can be increased over conventional crops, although this was not an expectation with current transgenic traits. Qaim [46] observed that insecticide reduction and yield effects are closely related: farmers who use small amounts of insecticides in their conventional crop in spite of high pest pressure realize a sizeable yield effect through Bt adoption, whereas the insecticide reduction effect will dominate in situations when farmers initially use higher amounts of chemical inputs. Even when approved, transgenic crops will only be grown if farmers perceive an economic benefit from doing so, currently usually related to a specific pest threat or weed burden or other rotational benefits.

The advantage to farmers of herbicide-tolerant transgenic crops (soyabean, canola/oilseed rape and sugar beet) generally applies over wider and more constant growing areas than the advantage of insect-resistant transgenic crops, and the advantage is affected by choice of crop rotation sequence. In situations where reductions in soil preparation time are related to minimum or no-till permit

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TABLE 8

Estimated benefit to EU of adoption of transgenic crops per crop cycle

Crop	Area, Mha	Trait	€/ha		€M	
			min	max	min	max
Maize[a]	8.5	IR			157	334
Cotton	0.26	IR	50	150	13	39
Soyabean	0.5	HT	10	38	5	19
Oilseed rape	6.5	HT	30	49	195	318
Sugarbeet	1.46	HT	50	150	73	219
Total					443	929

Benefits for other crops based on benefits from similar crops elsewhere in the world.

[a] Benefits for maize from Table 4, based on published outcomes for Bt maize in EU, but obtained before recent increases in pressure arising from spread of WCR.

changes in farming system, the associated economic benefit can be considerable [67]. Apel [68] made the further point that there is an indirect cost to subsistence farmers arising from European insistence on regulatory barriers to transgenic technology. The costs to the technology providers of compliance are so high that they put the few large companies that can afford those costs in monopoly positions. Subsistence farmers are thus denied the reduction in seed cost that competition between seed providers would create.

Paarlberg [69] showed that self-interest could explain an inconsistency in Europeans' attitude to genetic modification: he noted that while fewer than 1% of Europeans, just a few of the farmers, stood to benefit from transgenic crops, all Europeans are vulnerable to diseases treatable with medication developed with genetic modification. By 2006, the European Medicines Agency had approved 87 recombinant drugs derived using some aspect of genetic engineering. The 'precautionary principle' used to block approval of transgenic crops was set aside in approving the recombinant drugs. Potrykus [70], in reviewing lessons from involvement in developing 'Golden Rice', found no scientific justification for regulation based on extreme interpretation of the precautionary principle, and pointed out that the alternative of science-based assessment of traits would be economically advantageous for all parties, as well as being a moral imperative in view of the avoidable prevalence of malnutrition among those dependent on rice as their basic diet, a view endorsed by Qaim [39]. Von Braun [71] suggested that the risks of growing transgenic crops should be compared with the risks of non-adoption represented by negative externalities that hurt the poor, with non-adoption requiring greater commitment of 'environmental capital' to expand food supply.

For each of the five crops considered, there is considerable uncertainty about the size of the crop area in which transgenic traits offer economic advantage, and also the predicted benefit per unit area. In all cases, a premium has to be paid by the farmer to access the transgenic biotechnology, together with the cost of compliance with EU coexistence regulations, and in a few instances a transgenic crop has been found to give less yield than a conventional crop, for example as reported by Marra *et al.* [42] in relation to the early experience with Roundup Ready soyabean in some states of the USA.

Marra *et al.* [42] commented that even when there was a slight yield disadvantage with some HT varieties, the reduced herbicide costs and the extra time available to attend to a farmer's higher-value crops were more than sufficient to ensure rapid adoption. In a series of trials in South Africa, Bt maize efficiency was in some circumstances lower than for conventional maize, as reported by Gouse *et al.* [72], who commented that this is quite possible in a dry year, when stalk borers are not much of a problem.

Experience with Bt maize provides ex-post data for the estimation of crop performance; for maize, it is the variability of pest pressure from year to year, coupled with the rate of geographical spread of pest infestation, which is the major uncertainty. Brookes [31] reported commercial farms growing Bt maize between 2003 and 2007 delivered an increase in average gross margin profitability of €114/ha. The data from Brookes [27] on the variability of pest pressure on maize crops around Europe in 2007 are consistent with results of the analysis of Marra *et al.* [42] of data for Bt maize grown in states across the 'corn belt' of the USA in the years 1997–2001. It is assumed that the net benefit of adoption of Bt maize around Europe would vary to a similar extent from year to year, with almost no benefit when pest pressure is low, but major benefit in seasons of exceptional pressure, and significant benefit spread over several years.

Forecasting the benefit from herbicide-tolerant transgenic crops is easier in that the input savings are more reproducible from year to year as weed pressure in a given area is more predictable than pest pressure. Consistently beneficial agronomic performance of HT soyabeans in Argentina, and the brief but successful cultivation of HT soyabeans in Romania, indicate a strong probability of economic advantage for farmers if they were allowed to cultivate the crop in EU. For oilseed rape, the lower net benefit of €30/ha used for the calculation in Table 8 is only about 5% of the typical gross margin for the crop [32]. Transgenic Canola is so strongly favoured by farmers in Canada that a positive benefit seems very probable.

There is widespread interest in adopting HT sugarbeet. As reported above, changes in EU Sugar Regime have created a strong incentive to improve margins in a manner such as is offered by weed management in HT sugarbeet cultivation. Recent experience with similar adoption in USA will give farmers confidence that risks are relatively minor, and here also the uncertainty may be considered asymmetric, with greater likelihood of better than expected return.

Table 8 summarises the estimates made above of the revenue that could have accrued to European arable farmers if adoption of

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the crops discussed had been permitted. Table 8 shows the area over which transgenic traits would be beneficial, and, in columns 4 and 5, the estimated minimum and maximum likely benefit per hectare from evidence presented above. Columns 6 and 7 show the corresponding range in annual revenue if the transgenic varieties had been adopted over the entire relevant areas. The totals of columns 6 and 7 indicate the cost to European farmers of the regulatory constraint. On the basis of the areas of transgenic maize, cotton, soyabean, canola/rape and sugarbeet that could potentially be grown if more widely available we estimate gross margin improvements to the industry of between €443 and €929 M/year, as shown in Table 8. Essentially this can be viewed as revenue foregone by EU farmers who are not accessing this important technology. Continued non-use of the technology is essentially reducing the competitive advantage of EU farmers on world markets. As new events continue to come to market this gap could potentially widen. With growing demand, the soyabean area cultivated, for example, might expand rapidly if transgenic soya were approved for cultivation.

Despite these potential benefits there are clearly challenges to be faced with the growth of transgenics in the EU, mainly associated with managing co-existence and potential resistance management costs. These are generally issues within the productive agro-ecosystem rather than having larger scale ecological impacts. Kershen and McHughen [73] included discussion of coexistence, for example, in a review of economic concerns arising from adventitious presence of foreign matter in an agricultural commodity consignment. With regard to approved transgenic crops, the issues were not food safety or environmental protection but contract specifications and consumer preferences. Beckie and Hall [74] found that experimental results and modelling predictions for out-crossing in rape, maize and wheat revealed that an extended isolation barrier is only required between fields of less than about 5 ha to maintain gene flow below the EU threshold; and even for these small fields a 50 m barrier is sufficient. Davison [75] highlighted inconsistency among member states of the EU in the formulation of coexistence regulations on buffer zones and isolation distances, in spite of the creation of the European Coexistence Bureau established jointly by DG Agriculture and EC Joint Research Centre's Institute for Prospective Technological Studies. Devos *et al.* [76] noted that it was the European policy of subsidiarity that allowed member states to stipulate distances ranging between 15 m and 800 m ostensibly to ensure less than 0.9% of transgenic maize in conventional maize.

In relation to resistance management, in both sets of crops, there are potential problems with insects or weeds developing resistance to treatments; these problems are increasingly well understood [77,78], and in most cases the provision of untreated refuge areas delays or even prevents the onset of resistance. Another option is becoming available in the form of stacked transgenic traits [79] which can substantially reduce the statistical probability that resistance will develop. Set against these two issues consideration needs to be given to the potential impact of climatic change and the impacts this may have for maintaining production across a wide spectrum of crops. New transgenic varieties, many with stacked traits, may have clear agronomic benefits for farmers in marginal environments where increased climatic variability could have a significant impact on yields.

Conclusions

To date the growth of transgenics in the EU has been limited, despite examples of potential benefits in, for instance Spain with respect to maize, and in the past Romania with respect to HT soya. Predicting where currently available transgenic events could have agronomic and/or economic benefits across the EU is difficult and the data we present here are estimates. Our research suggests that at present the revenue foregone is relatively small in relation to overall economic output of agriculture; however, other research has suggested that the growth of transgenic crops may have a range of other benefits related to sustainability [9].

At present the only transgenic crop that is being commercially cultivated in the EU is Bt maize and only one variety MON810 is available to growers; a second variety, T25, is approved but not placed in the market. Thus the potential for farmers to grow transgenic crops is currently extremely limited. Approval processes are both rigorous and extremely slow suggesting short term choices for farmers in the EU, with respect to transgenic crops, will remain limited.

Given that established transgenic traits already reduce pesticide loading and appear in some cases to increase yield and economic income in many parts of the world, it could be regarded as negligent to ignore such technology given the environmental, food security and population growth issues that are currently challenging governments across the world. As new events are released which may include salt tolerant, drought tolerant, nitrogen efficient and nutritionally enhanced varieties it seems unlikely that the EU can reasonably continue with its current severe restrictions that inhibit progress in the area. While revenue foregone and practical benefits appear at present limited for EU farmers, continued denial of these transgenic options to farmers in the EU will lead to decreased competitiveness that at some point will require redress.

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