SESSION 5

WORKSHOP II – *DIABROTICA*: A CASE STUDY OF AN INVASIVE SPECIES

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Western corn rootworm (*Diabrotica virgifera virgifera*), its potential spread and economic and ecological consequences in Germany

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ABSTRACT

Western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) has an important natural spreading potential in Europe. In 2003, this maize pest was introduced in five locations in West Europe, one of them being Blotzheim in Alsace (France) near the German border. A simulation of spread, starting from the introduction point in Alsace, over ten years, results in an infested area of 1.3 million ha of maize, with France at 830,000 ha and Germany at 400,000 ha of maize most affected. In the Federal Land of Baden-Württemberg, WCR would infest nearly the entire maize area (more than 140,000 ha over ten years). More than 38,000 ha of maize are at high risk, i.e. economic damage is expected. A total pecuniary loss of about 20 million Euro over one decade would accumulate over the considered period of spread period in the high-risk areas of Baden-Württemberg.

INTRODUCTION

The western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) was probably introduced to Europe in the end of the 1980s and, in 1992, it was first recorded near Belgrade Airport (Serbia). The beetle is native in North America and is one of the most destructive maize pests in the USA. It costs about US$ 1,000 million (treatment costs and crop losses) each year (Krysan & Miller, 1986). Furthermore, it is the insect pest which results the greatest use of insecticides in the world. Because of its huge economic importance for the maize growers in Europe it is a quarantine pest, regulated by the European Union (EU) in EC Directive 2000/29/EC and in Commission Decision 2003/766/EC.

WCR could spread by hitchhiking, by means of traffic such as airplanes, or (as it is a good flyer) by natural flight. Transportation by hitchhiking has opened the beetle to reach new territories, in spite of the ecological barriers (oceans, mountain chains, connected regions without maize). The probability for an establishment in case of a new introduction is dependent upon the presence of nearby maize growing. Furthermore, only a high concentration of maize (that means maize after maize in the crop rotation), allows multiplication, increasing abundance and, subsequently, increasing pressure for further spread.

In 2003, WCR was introduced in the Alsace region in France, near the German border in Baden-Württemberg. In spite of eradication measures in France (focus and safety zones) and Germany (safety zone), the scenarios of spreading for over a decade without any measures (natural spread) were initiated. The economic and some ecological consequences for Germany, especially Baden-Württemberg, have now been examined.

METHODS

The dispersal rate of the WCR in Europe was analysed, starting with the introduction to Serbia in the beginning of the 1990s. The dispersal rates of the WCR differed from year to year. The spreading rate of the WCR ranged from 60 to 100 km/year, without any assistance measures (= natural spread). The simulation model used as an average a maximum spreading rate of the population of the WCR of 80 km/year without any assistance measures. The maximum spreading rate is reached by WCR in the succeeding year only if continuous maize is available in the infested area. The concentration of maize in crop rotation is the main factor in the simulation model (Baufeld & Enzian, 2005). In the case of a low maize concentration, the multiplication factor and spreading pressure are very low. In that case we reduced the spreading rate by a correction factor K, which is defined as follows: in case of >= 50% of maize in crop rotation K = 1 and

in case of < 50% of maize in the crop rotation: $$K = \frac{\text{concentration of maize in \%} \bullet 2}{100}$$

The following formula was used in the simulation model to calculate the spreading rate of WCR: $AR = FD \bullet K$

where AR = spreading rate of WCR
FD = distance of flight without containment measures (80 km/year)
K = correction factor (see above)

Furthermore, the topography was analysed in the infested areas of south-east Europe. The analysis showed that WCR adults are not able to fly regularly above altitudes of 900 m, which was considered in the simulation model. The lowest mountain chain in Western Europe is up to 800 m and has valleys (often with maize) which favour progressive dispersal. Tunnels (as in Switzerland) could have also an influence on the spread, but were not considered.

All information is utilised in the simulation model on the spreading of WCR. Calculations are carried out on the basis of GIS software ArcView/ArcInfo. The model was used to simulate the spreading rate of WCR over ten years. Starting from the newly infested location Blotzheim, near airport Basel-Mulhouse (located 4.7 km from Germany and 4.8 km from Switzerland), in Alsace (France) in 2003, the spread was simulated without eradication or containment measures (natural spread).

The assessment of the economic consequences and the impact on ecological aspects based on the above-described spreading scenario was restricted to the Federal Land Baden-Württemberg. Pecuniary losses were analysed for 10 years of spread. Damage due to WCR is expected in the 5^{th} to 7^{th} year. This conforms with findings from the USA and Hungary (C R Edwards & J Kiss, personal communication). Because of this delay we assumed economic damage occurred in the 5^{th} year. The concentration of maize in a crop rotation is the main factor for reaching a high abundance of WCR, and also for the calculation of crop damage and pecuniary losses. Therefore, continuous maize is the precondition for fast multiplication of the population of WCR. In this case, spreading pressure is high, and reaching population densities above the economic threshold is going on more rapidly. As a result, we would have a larger infested area and higher economic damage per unit of time. We assumed that regions containing more than 50% of the arable land in maize would have significant areas in continuous maize, and we defined these areas as 'areas with high risk' (Schaafsma *et al.*, 1999). For avoiding greater mistakes, especially for larger regions such as provinces, we consider areas with 50% of maize in the crop rotation as being high-risk areas.

Baden-Württemberg had 141,692 ha of maize in 2003, with 72,883 ha (51.4%) of grain maize + corn cob mix (CCM) and 68,809 ha (48.6%) of silage maize (from Statistische Berichte Baden-Württemberg, 2004). To assess the potential damage, yields were separately considered for grain maize + CCM and for silage maize. This was necessary because of the different yield of grain maize + CCM and of silage maize, but also for further calculation of the pecuniary loss. The basis for the calculation of the potential yield loss for Baden-Württemberg for grain maize + CCM was 8.72 t/ha and for silage maize 42.73 t/ha, and the gross value was 111.20 Euro/t and 23.40 Euro/t, respectively (from Statistische Daten, Regierungspräsidium Freiburg, 2004)

WCR infestation has been shown, over a longer time period, to decrease yields of maize by 10–13 % (Schaafsma *et al.*, 1999). However, in some cases the damage could be much higher and result in a 30% yield reduction (Sivcev & Tomasev, 1999). In the following, the yield loss was calculated at only 10% for high-risk areas (Schaafsma *et al.*, 1999).

RESULTS

The simulation showed (in the absence of controlling measures) the dramatic ongoing spread across the borders of France, Switzerland, Germany, Belgium and Austria, along the high concentration of maize in Alsace and in the Rhine valley in Baden-Württemberg (Figure 1). WCR finds ideal conditions for multiplication in this region, and the pressure for spread would be high in the case of non- eradication measures. As a result of the simulation, over one decade, a total maize area of 1,354 million ha would become infested by WCR in the above-mentioned countries. France would have the largest area of infested maize (with c. 830,000 ha), followed by Germany (c. 400,000 ha), Switzerland (c. 58,000 ha), Austria (c. 41,000 ha) and Belgium (c. 25,000 ha).

Of the 400,000 ha of infested maize in Germany, Baden-Württemberg would account for c. 140,000 ha, which is nearly the whole maize growing area in this region (currently, 141,700 ha); of this, 38,585 ha are in high-risk areas, representing more than one quarter (27.2 %) of the whole maize area. The high-risk area consists of 92.2 % of grain maize + CCM and 7.8 % of silage maize. This would lead, in the first instance, to economic damage to grain maize production in the Baden-Württemberg region. A high-risk area of 35,267 ha of grain maize + CCM (but of only 2,984 ha of silage maize) would be infested by the WCR in Baden-Württemberg (Table 1). Over the whole one-decade period, in this region, a high-risk area of 187,980 ha of grain maize + CCM and 15,903 ha of silage maize (in total more than 200,000 ha of maize) would be infested by WCR.

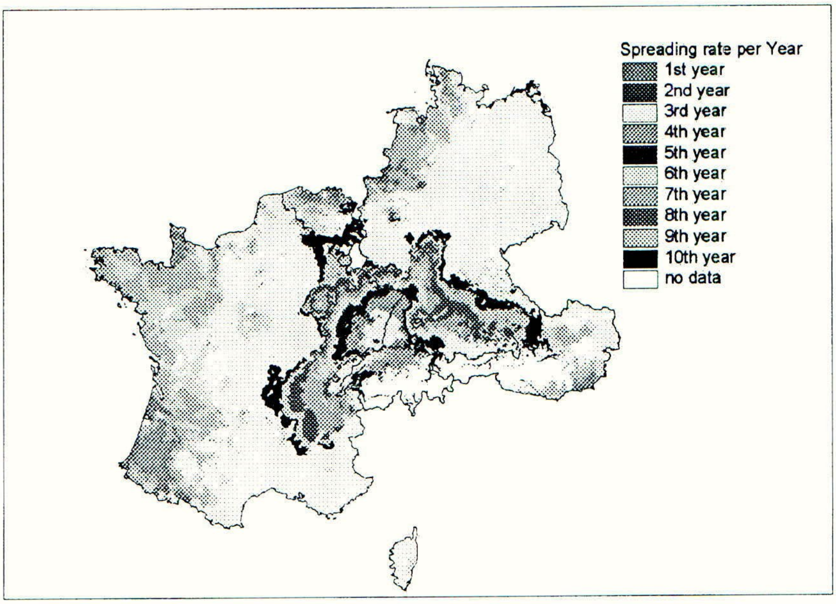

Figure 1. Cross-border spreading scenario for western corn rootworm (*Diabrotica virgifera virgifera*) over 10 years, starting from Blotzheim (Alsace, France), without eradication and containment measures (natural spread).

Economic damage due to the WCR is expected only in high-risk maize-growing areas. Assuming only 10% yield loss, this would lead to an accumulated loss of 163,918 t of grain maize + CCM and 67,953 t of silage maize over the considered period (Table 1). WCR would cause an accumulated pecuniary yield loss of 18.2 million Euro for grain maize + CCM and 1.6 million Euro of silage maize for Baden-Württemberg. The annual loss after 10 years would be 3.7 million Euro within the 38,585 ha high-risk areas maize in Baden-Württemberg. The total loss in this region would grow to 19.8 million Euro over one considered decade.

CONCLUSIONS

WCR is a damaging maize pest not only in its native area. In the Alsace region, WCR would find ideal conditions for establishment, multiplication and spread. Eradication, as carried out in France and Germany in the last two years, prevents establishment and, subsequently, avoids the high economic losses shown in the simulation of spread. However, if measures were not successful or were not carried out for a decade, this would lead to infestations of large areas (and not only in France). Although not in all infested maize areas, economic yield losses from WCR are to be expected. Mainly in high-risk areas, yield losses would occur above the economic threshold of 1 beetle/maize plant. In these regions farmers would be affected and suffer yield loss, which would increase over a longer period. In Serbia, in some regions with a high concentration of maize, WCR caused up to 30 % yield loss; furthermore, in some years (as in 2003) 90% yield loss is possible (southern Hungary).

Table 1. Effects over 10 years, owing to cross-border spread of western corn rootworm (*Diabrotica virgifera virgifera*), starting from Blotzheim (Alsace, France), without eradication and containment measures (natural spread).

Year	Infested maize areas		Yield loss		Pecuniary yield loss		Total loss
	Grain maize (ha)	Silage maize (ha)	Grain maize (tonnes)	Silage maize (tonnes)	Grain maize (Euro)	Silage maize (Euro)	Maize (Euro)
1 + 5	0	0	0	0	0	0	0
2 + 5	0	0	0	0	0	0	0
3 + 5	6,440	545	5,616	2,328	624,054	54,479	678,533
4 + 5	11,558	978	10,079	4,178	1,119,967	97,771	1,217,738
5 + 5	17,175	1,453	14,977	6,209	1,664,214	145,282	1,809,496
6 + 5	23,623	1,998	20,599	8,540	2,289,013	199,826	2,488,838
7 + 5	27,319	2,311	23,822	9,876	2,647,122	231,088	2,878,210
8 + 5	32,021	2,709	27,922	11,575	3,102,733	270,862	3,373,596
9 + 5	34,575	2,925	30,149	12,499	3,350,212	292,466	3,642,678
10 + 5	35,267	2,984	30,753	12,749	3,417,280	298,321	3,715,602
Total	187,980	15,903	163,918	67,953	18,214,595	1,590,096	19,804,691

Yield loss can be avoided by insecticide use or crop rotation. In the USA, farmers initially turn to the former, which leads to a huge amount of insecticide usage in agriculture. Considered world-wide, WCR is the pest which requires the greatest amount of insecticide use overall (Pershing, 2001). Data from Ontario, Canada, showed a mean of more than 50% continuous maize, with an area of about 32% treated with insecticide against WCR (Schaafsma *et al.*, 1999). If the same potential rate of insecticide use against WCR is assumed for Baden-Württemberg, then (within the high-risk area of maize of up to 38,251 ha) there is potential to treat up to 12,240 ha annually. However, the potentially infested maize area could increase over the time, and lead to even greater insecticide use. Apart from the need to treat against European corn borer (*Ostrinia nubilalis*), which is not established in all maize-growing regions in Germany, insecticide use in maize is uncommon. The use of insecticides against WCR would reduce the income of farmers and would also be an additional and unwelcome environmental burden.

The most effective measure to control the WCR is crop rotation. By not growing maize after maize, WCR abundance is reduced drastically. Although some of the females lay eggs outside maize fields, R C Edwards & J Kiss (personal communication) estimate that from 3 to 5% of the eggs are laid in crops other than maize, the population density would dip below the economic threshold; usually, it is then no longerr necessary to control WCR with insecticides. If a crop rotation has only two crops (as in the USA), rotation with soya beans as an adaptation to this special situation is possible. The progeny of WCR adults which lay eggs in soya bean crops will survive, and the selection pressure of populations which lay the eggs in this other crop will increase. Where there is a strong two-crop rotation, this could also happen in Europe. However, a three-crop rotation avoids this disadvantage, and no further selection pressure is possible. WCR will then drop below the economic threshold, so this maize pest no longer needs to be controlled by insecticides. It is acknowledged, however, that a sudden shift from maize monoculture to crop rotation is difficult for farmers to realise; there is no alternative crop with the same yield of energy and quality.

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Surveying and monitoring western corn rootworm (*Diabrotica virgifera virgifera*) in England & Wales

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ABSTRACT

The pest risk assessment for western corn rootworm (*Diabrotica virgifera vergifera*) indicated that this species could become established on maize crops in southern England, but it was unlikely to cause significant economic damage. The first beetle was caught on 28 August 2003, in a maize field near London Heathrow airport. In 2003, c. 350 pheromone traps were placed on 80 farms and 92 adults were trapped. In 2004, c. 1,700 traps were placed in maize fields throughout the UK, including the demarcated zones near Heathrow and Gatwick airports. In total, 87 adults were caught in 2004, but despite extensive trapping there were no findings on new farms, either in the existing focus zones or in the rest of the country. Commission Decision 2003/766/EC was followed in respect of the UK incursions, as far as was practicable. Crop rotation, delayed harvest of the affected area in relation to maize in the surrounding area, and chemical treatments, were all required; additional trapping was also done. Some measures however, such as the ban on moving harvested material, could not be applied in the agronomic systems operated by many growers in Southeast England.

INTRODUCTION

Since it was first found in Europe – near Belgrade, in 1992 – the Defra Plant Health Service has kept a precautionary watch on the spread of western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) across the Balkans and into central Europe. No clear entry pathway was identified, although the evidence from satellite outbreaks in mainland Europe strongly suggested a link with airports. Measures were drawn up: i) a monitoring programme covering sites of greatest risk in southern England, and ii) an outline contingency plan in the event of an isolated find, or larger outbreak. Reports of WCR captures near two Paris airports appeared in August 2002, raising concerns in many northern European countries. A decision was taken immediately to implement the monitoring programme in southern England in 2003. Additionally, the pest risk assessment was extensively revised, e.g. taking account of the large increase in the area of maize grown in the UK during the 1990s.

During August and September 2003, WRC was again trapped near Paris, and new outbreaks were confirmed in the Alsace region of NE France. In addition, more outbreaks were reported near other airports: e.g. Schiphol (Netherlands) and Zaventem (Brussels, Belgium). During the spring and autumn of 2003, the EU introduced legislation for harmonized surveillance, eradication and containment of WCR. Decision 2003/766/EC called for crop rotation, delayed harvest of the affected area in relation to maize in the surrounding area, and chemical treatments. Additional trapping measures were also put in place. This paper reviews the surveying and monitoring programmes for WCR in 2003-04.

NATIONAL SURVEYS

In late July 2003, monitoring traps were placed at 30 locations in southern England to determine the possible presence of WCR (Figure 1). Csalomon® sticky cloak, pheromone (PAL) traps (Dr. Miklós Tóth, Hungary, http://julia-nki.hu/csalomon) were placed in maize fields within a 10 km radius of civilian and military airports, which were considered as high-risk sites for invasion, based on the concentration of maize in the area and the volume of freight handled by the airport. Initially, the survey required three visits by the Plant Heath & Seeds Inspectorate (PHSI) to each trap site: setting up the 1st trap (end July), collecting the 1st trap and replacing with 2nd trap and lure (early September) and finally collecting the 2nd trap (mid-October). However, following the detection of the beetle, visits were much more frequent: at least every two weeks. It was recommended that traps were placed at least 5–10 m from the edge of the field, with at least two traps per site, not less than 30 m apart.

In late August/early September 2003, the pest was confirmed from forage maize crops at four

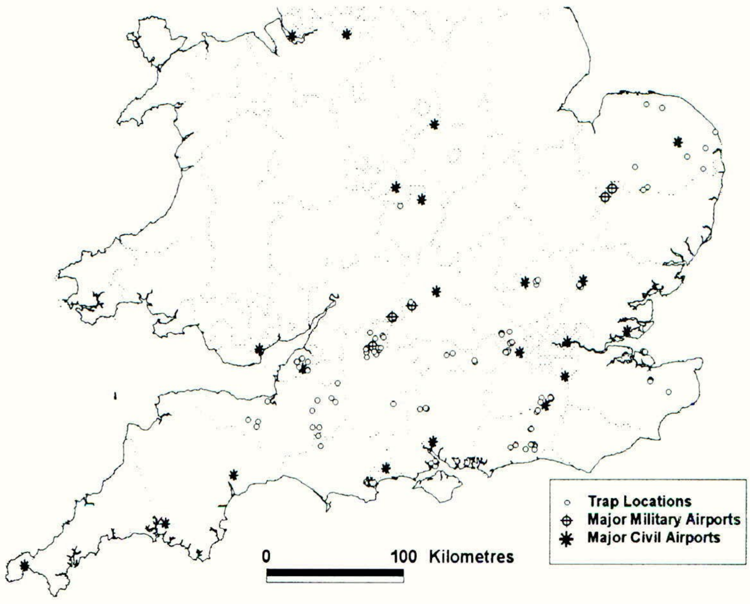

Figure 1. *Diabrotica virgifera virgifera* – locations of airfields and pheromone traps, 2003.

farms near Heathrow airport and one near Gatwick airport. A total of 57 adult male WCR were found on 28 August, on two pheromone traps at a maize field site, NW of Heathrow airport; 42 beetles on one trap and 15 on the other. Many of these beetles had clearly been present on the trap for some time, showing signs of blackening and decay. There were however, also some freshly caught beetles at the time of the visit, indicating that the flight period had not ended. Following the first finding of the pest, the number of traps was rapidly increased, extending the sampling to an additional 50 locations in what remained of the season. In total, c. 350 traps were placed on 80 farms in 2003; these also included fields of grain maize, game cover maize and sweet corn in sites away from airfields (Figure 1). None of these extra traps caught any WCR, but as they were erected after the optimal flight period of the beetles, the presence of the pest in a wider area could not be discounted.

In total, 92 WCR were found in 2003, comprising 90 male and 2 female beetles (Ostojá-Starzewski, 2005) (Table 1). Most (95%) were caught in, or immediately surrounding, a large (c. 28 ha) area of maize, NW of Heathrow airport. The maize was divided into three fields, bisected by ditches/watercourses, lined with hedgerows and large trees. Additional floral and pheromone traps were erected in and around this site on 13–14 September, including modified funnel VARs+ traps, yellow PALs traps and standard yellow sticky traps. The two female beetles were caught with cucurbitacin, or floral, bait traps.

UK Statutory Action required, when WCR beetles were confirmed, the following:

1) In fields in which beetle capture has taken place, a pesticide application of chlorpyrifos as soon as possible after harvest and no maize to be grown for the next 2 years.
2) In all other fields in focus zone, i.e. within 1 km radius of capture field, a crop rotation whereby during any period of three consecutive years following the issue of the Notice, maize is grown only once in the field. In addition, where a maize crop is sown in a field that grew maize the previous year, insecticide-treated maize seed must be used.
3) In all fields in the safety zone – an additional 5 km radius – maize is grown only once during any period of two consecutive years following the issue of the Notice; or, in cases were rotational requirements caused hardships, the use of insecticide-treated maize seed was offered as an alternative.

Some additional measures however, such as the ban on moving harvested material, could not be applied in the agronomic systems operated by many growers. They depended on the crop being transported to the farm clamp, for feeding to stock at a later date, and it was essential in these cases to harvest and process the maize *in situ* and transport it in the processed form.

In 2004, a more extensive national survey was carried out. Multi-criteria analysis was used to assess the likelihood of the presence of WCR in each of the 10 administrative sub-zones of the PHSI. Criteria considered were: i) transport routes (civil and military airports; docks; the channel tunnel and associated motorways); ii) climatic suitability for pest establishment (development/survival), and iii) area of maize and number of holdings. These criteria were scored on a scale of 1–10 and summed to obtain a measure of relative risk. Traps were apportioned to sub-zones in relation to the relative risk. Each sub-zone received from 7 to 14% of all traps (i.e. 70 to 140 per 1,000 traps). In total, over 1,700 pheromone traps were placed in maize fields throughout the UK in 2004 (Table 1). Traps and lures were replaced after c. 6 weeks in the demarcated zones, i.e. a 12-week monitoring period (early July to early October). The aim of the national survey however, was to target only adults in the main flight season; therefore, pheromone traps were erected for only 6 weeks (late July to early September). WCR was confirmed as still present in the zones demarcated in 2003, despite the implementation of rotation and other measures. A total of 87 beetles (all males) were caught on 40 PAL traps in 2004, compared with 92 beetles on 19 traps in 2003. All traps from the national survey were negative, with no new findings of the pest in the rest of the country in 2004.

Table 1. Numbers of *Diabrotica virgifera virgifera* beetles caught in the UK (2003–2004).

Year	Number of monitoring sites	Number of pheromone traps	Number of farms with WCR	Number of positive traps	Number of beetles
2003	80	350	5	19	92
2004	490*	1,700$^{\oplus}$	4	40	87

*Regions (40); demarcated zones (200); national survey (250); $^{\oplus}$Regions (150); demarcated zones (400); national survey (1,150).

In the devolved administrations and Crown Dependencies, PAL and PALs (Northern Ireland only) traps were placed in the following numbers of maize fields: Northern Ireland (20 traps in 10 fields), Guernsey (16 traps in five fields); Jersey (20 traps in maize fields and at the ports), Isle of Man (6 traps in three fields) and southern Scotland (30 traps in eight fields) (Anon., 2004). No WCR were detected at any of these sites.

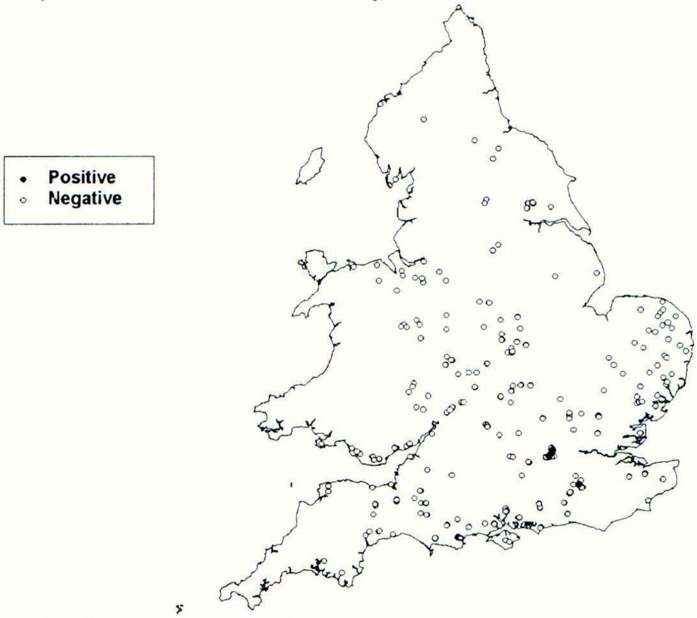

Figure 2. *Diabrotica virgifera virgifera* – national survey locations of pheromone traps, 2004.

HARVESTING AND STATUTORY MEASURES

Harvesting commenced on 13 September 2003 at the main 'outbreak site' near Heathrow; the soil was very dry, and the weather was warm and sunny (max. temperatures of 24–26°C) on both days. A fleet of 7 tractor-trailer units was used to transport the maize 13 km north to the farm clamp. A Statutory Notice required that all harvested maize be transported "in trailers which contain the crop and minimize the risk of beetles escaping". The contractor was asked not to fill the wagons to the top. Samples of crop debris, which had accumulated on the front of the forage harvester, were taken for sorting and analysis. Large numbers of live, intact invertebrates were observed in this detritus, including spiders, harvestmen, beetles, bugs and aphids, but no WCR. During harvesting, the whole maize was milled/chopped very fine (1 mm) as an additional precaution. Samples of the chopped-up maize crop were also analyzed in the laboratory; the stubble fields were extensively walked and inspected for live beetles; and a motorized vacuum sampler was used to sample the maize crop and the ground surface of both the cut and uncut crop. In all cases, no WCR were found.

Another Statutory Notice requirement was for a post-harvest application of the insecticide chlorpyrifos "as soon as possible after the harvest and in any event within 10 days of harvest to target any live beetles which may be crawling on the maize or on the stubble". Since only one chlorpyrifos formulation was approved for use on maize in the UK, CSL obtained Specific Off-Label Approvals (SOLAs) for the application of additional chlorpyrifos products, more readily available to farmers with fields in which WCR had been captured. In the event, it appeared very unlikely that any live WCR were present on the very dry, dusty maize stubble in mid-September 2003, and the requirement for a stubble spray was dropped in 2004. An emergency SOLA, for the use of lambda-cyhalothrin as a foliar spray on maize (and maize stubble) against WCR was also obtained. Authorization for emergency aerial pesticide application was not granted by Pesticides Safety Directorate, owing to the unacceptable risk of bystander exposure in the semi-urban outbreak area, compared with the risk posed by the pest.

DISCUSSION

Despite extensive trapping in 2004, there were no new findings of WCR on additional farms, either in the area where the pest was confirmed in 2003 or in the rest of the country. Thus, containment measures appear to have been successful in preventing the further spread of the pest. If eradication measures are to be continued, then the association with airports needs to be better understood. The logic of eradicating these outlying incursions (i.e. beyond the naturally spreading front of the pests range) seems to be that of gaining a few extra, pest-free years, before the spread encompasses the new region (Decoin, 2004). If however, the invasion of new colonists cannot be stopped, and will indeed gather momentum as the range expands in continental Europe, then eradication measures may have to become progressively more severe, in order to maintain pest freedom. In the UK, the costs of such measures will most likely outweigh the benefits (MacLeod *et al.*, 2005).

Under current climatic conditions WCR appears to be at the edge of its range in the UK (MacLeod *et al.*, 2004). However, maize is an increasingly important UK crop. There are currently approximately 7,000 growers in England – of whom 5,000 are located in the southeast, southwest and West Midlands – with over 100,000 ha grown for livestock forage, and perhaps a further 1,100 ha grown as sweet corn for human consumption. The summer of 2003 was one of the hottest on record: Heathrow (London) meteorological station reported a new station record high temperature of 37.9°C on 10 August (UK Met Office, www.metoffice.com/). The effect of this hot summer could have been to compress the flight period of the beetles and increase the incidence of environmental conditions suitable for take-off and flight by the beetles. Baker *et al.* (2003) suggested that by 2050 – under global warming – a large area of SE England would be suitable for this species.

The range of insecticides approved for use on forage maize in the UK is more limited than in many other European countries. Specialized equipment designed to spray mature maize crops is not available in the UK and ground-based spray applications using inappropriate machinery would cause considerable damage to the crop. The aerial application of insecticides to target adults during the flight periods was also ruled out. Thus, state-funded aerial applications of deltamethrin, which were reportedly applied to maize fields in the focus zones near airports in continental Europe, were not possible in the UK.

The situation in the UK is not dissimilar to that in other northern European countries, such as Belgium. For example, the pest was first detected in both countries in 2003, and in 2004 all new infestation sites were located within existing buffer zones. The total number of traps used in each country in 2003 was also very similar: 353 (Belgium) (www.favv-afsca.fgov.be); 350 (UK). In France, during the first year of detection (2002), the countrywide WCR survey network included 284 sites (Reynaud, 2002), whereas in 2004 there were 480 sites, selected on the basis of risk (Klinger, 2004). The number of traps used and selection criteria for locating them were similar to that in the UK national survey.

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Spread and population development of western corn rootworm (*Diabrotica virgifera virgifera*) in Austria

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ABSTRACT

The western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) was discovered for the first time in Austria on 10 July 2002. A monitoring programme established in 1999 was greatly intensified after capture of the first beetles, and subsequently extended to all provinces. Spread in 2003 was moderate, but it expanded rapidly in 2004, covering parts of the provinces of Burgenland, Lower Austria, Styria and Vienna. At present, the known range of WCR covers c. 8,000 km^2, about. one-tenth of the country. Monitoring of eggs and larvae gave no results, but the presence of these stages is indicated by captures of adults in emergence cages. WCR population growth is documented by large increases in trapped beetle numbers over the 2002–2004 time period. A comparison of one-, two-, three- and four-week pheromone trap replacement showed that captures already decrease markedly in the second week.

INTRODUCTION

The western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) was first detected in Europe in 1992, near Belgrade airport in Serbia (Baca, 1993). Since that time it has spread continuously in south, east and central Europe, and has been recorded in isolated outbreaks in some southern and western European countries. Its first detection in Austria occurred on 10 July 2002; the monitoring system was immediately intensified in that year and extended to the whole country in the subsequent years (Cate, 2002). Thus, spread and population development of the pest in Austria is well-documented, which could be helpful for other countries to assess developments, if and when they also become infested.

MATERIALS AND METHODS

Adult monitoring

Monitoring of adults began in 1999, first using cucurbitacin traps and, later, pheromone traps. Since 2002, only Csalomon® PAL pheromone traps have been used, which allow comparisons between the trapping stations to be made. In 2002, monitoring was done by the Federal Plant Protection Service (FPPS) in Lower Austria and northern Burgenland, and by the provincial Plant Protection Services (PPPS) in some of the other provinces. In subsequent years, the PPPS of all provinces took over monitoring duties, and the FPPS served as a centre for coordination, counselling and information feedback.

Within the monitoring programme, pheromone traps are installed from the end of June/beginning of July to the end of September or harvest, respectively. Wherever possible, they are placed in continuous corn c. 10 m into the field. PPPS are advised to monitor in fields alongside asphalt roads, and to place traps in the same way in all fields and in as close to a grid form as possible, with a spacing of 5–10 km, depending on corn-growing intensity and distance from known infestations. This facilitates control of the traps, and reduces the time needed for control purposes. Geographic co-ordinates of all trapping stations are determined by GPS. In Austria, all traps are checekd on a weekly basis, and both traps and pheromones are exchanged monthly. The results are forwarded to the FPPS, where they are combined in a digital database and returned to the PPPS. Thus, the PPPS receives current information on monitoring results from the entire country, and can react accordingly when WCR nears their borders.

Further traps were installed after the initial detection of WCR in 2002, in order to determine the pest's exact distribution, thus bringing the total number of traps to 210. In 2004, trap numbers in northern Burgenland were reduced, owing to the fact that large areas of the region were already infested. Numbers of traps in each province were as follows:

- Burgenland – 113 in 2002; 351 in 2003; 226 in 2004;
- Kärnten (Carinthia) – 6 in 2002; 3 in 2003; 6 in 2004;
- Niederösterreich (Lower Austria) – 42 in 2002; 159 in 2003; 206 in 2004;
- Oberösterreich (Upper Austria) – 24 in 2002; 15l in 2003; 26 in 2004;
- Salzburg – 0 in 2002; 5 in 2003; 5in 2004;
- Steiermark (Styria) – 16 in 2002; 29 in 2003; 160 in 2004;
- Tirol (Tyrol) – 6 in 2002; 6 in 2003; 9 in 2004;
- Voralber – 0 in 2002; 10 in 2003; 22 in 2004;
- Wein (Vienna) – 3 in 2002; 3 in 2003; 7 in 2004.

This gave totals of 210, 581 and 667 traps in 2002, 2003 and 2004, respectively.

Egg and larval monitoring

First attempts to monitor WCR eggs in the soil were undertaken in 2004, using visual inspection and sieving/flotation techniques. The first method is very time- and labour-consuming, the second presented technical difficulties (owing to clogging of the sieves by the large number of fine particles in the soil).

Larval monitoring was undertaken in 2003 and 2004, whereby 10 consecutive plants in four rows per field were dug up, and the roots and surrounding soil visually examined for larvae. In 2004, experiments were conducted to try to attract neonate larvae in the field. In one experiment, plots of 3 × 3 m in the corn fields were cleared of plants, except for 1 corn plant in the middle. In a second experiment, all plants were cleared and plastic pots with 56 holes on the bottom and sides and filled with 21.3 g maize kernels, were placed in the soil in the middle of the plots. The kernels had been allowed to germinate and grow for 1 week in the laboratory before the pots were placed in the field. The pots were checked and replaced weekly.

DISCUSSION

Adult monitoring

The results of adult monitoring are presented in the following three maps (Figures 1–3). Maps were drawn up using the software program AustriaMAP 3D, a product of BEV (Federal Office of Meteorology and Surveying, Vienna, Austria).

In 2002, after the first detection of WCR in maize fields near the borders of Hungary and Slovakia, an intensive trapping regime was installed by the FPPS and the Burgenland PPS to determine extent of the pest's distribution. The pest was found along the Hungarian and Slovak borders in the northeastern region east of Lake Neusiedl. A surprisingly large population was also found near Parndorf, at the border with Lower Austria, the site of a seed-production factory. Furthermore, a few specimens were found in Lower Austria, north of the Danube border along the river March, which marks the border between Austria and Slovakia. A single specimen was also discovered in a trap in middle Burgenland (Figure 1).

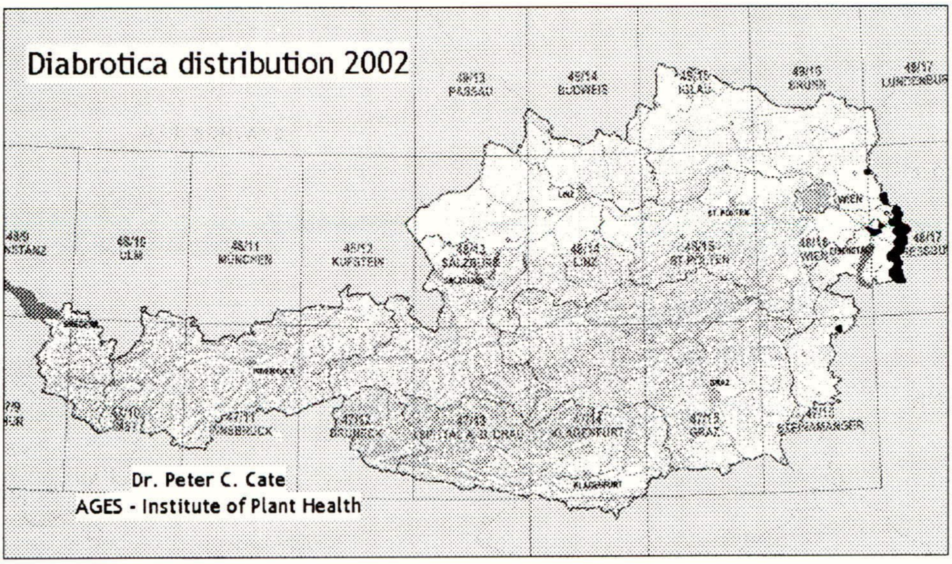

Figure 1. Distribution of *Diabrotica virgifera virgifera* in Austria in 2002.

It is evident that WCR is invading Austria from Hungary and Slovakia, where control measures are mandatory only after larval damage occurs. The population in the area of Parndorf could possibly have arisen from specimens carried there during seed-corn-production campaigns, as many fields of seed corn lie in the infested area near the Hungarian border. From the larger number of beetles caught it can be inferred that a minor infestation was already present in the area in 2001, even though no beetles were caught in the area during that year.

In 2003, further incursions occurred along almost the entire eastern border of Austria, for a length of 231 km. In Burgenland, there were new areas of infestation in the middle and southern portions, and the infestation in the northern part extended westward for c. 10 km. In Lower Austria there was almost no westward extension, except for some isolated trap locations, mainly directly on the border to Slovakia. From southern Burgenland, the pest spread to Styria, where it was detected at four locations (Figure 2).

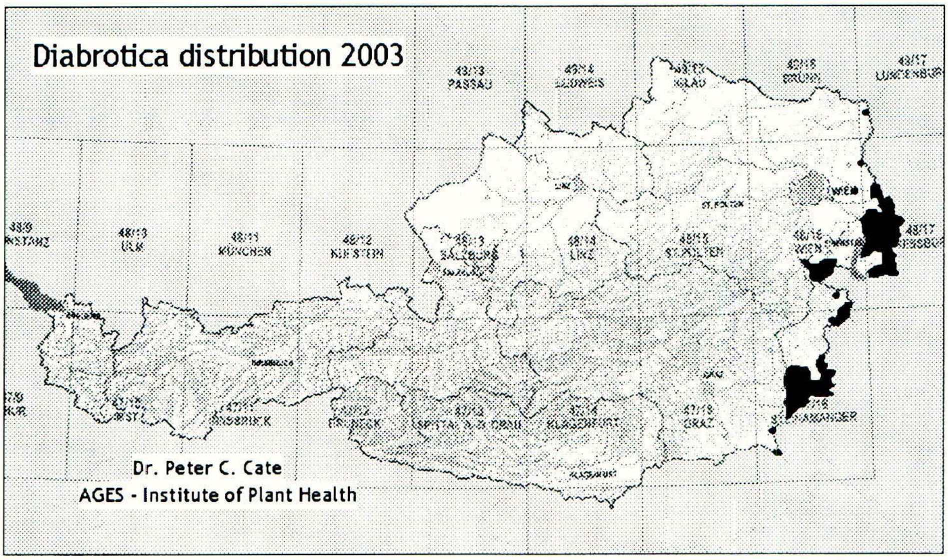

Figure 2. Distribution of *Diabrotica virgifera virgifera* in Austria in 2003.

In 2004, owing to adverse weather conditions, WCR development was retarded. Therefore, expansion of the WCR range occurred later in the season, but was more intensive than expected. Large parts of Burgenland, except for hilly regions in the middle part where little corn is grown, were completely infested. Lower Austria saw its greatest range extension to date, WCR moving westward by up to 40 km and reaching Vienna, where it was found in corn fields in the southern and northeastern parts of the city. Large areas of the southeastern part of the province are now also infested, a continuation of the pest's range in northern and middle Burgenland. The infestation in southern Burgenland extended further into southeastern Styria, a region of intensive corn-growing for animal fodder and seed-corn production. In this region range extension was c. 20 km. The area of the country now infested is c. 8,000 km^2, which is about one-tenth of the area of Austria (Figure 3).

Egg and larval monitoring

No eggs were found by either technique, and despite the problems encountered it is believed that the WCR egg population is still too low to be monitored successfully.

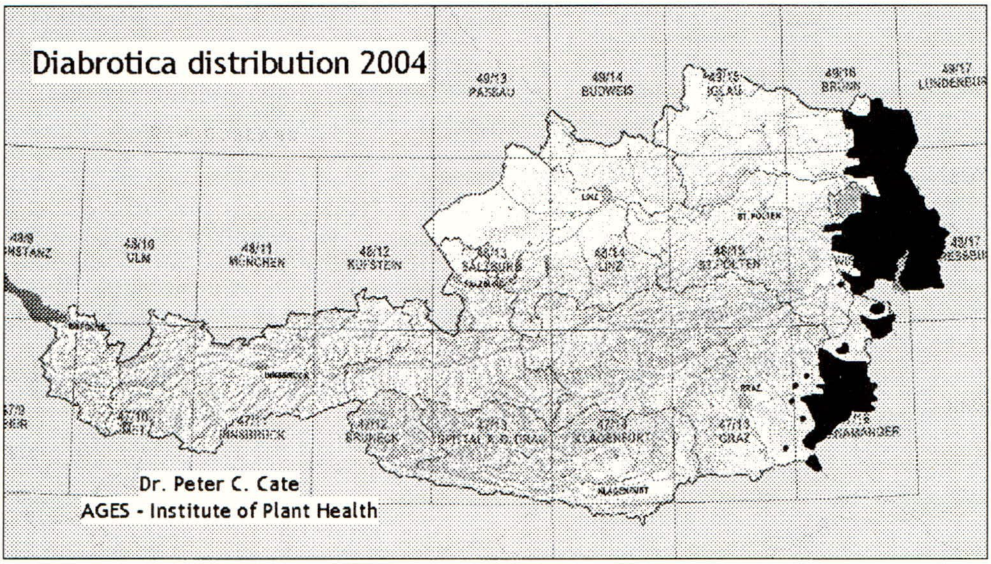

Figure 3. Distribution of *Diabrotica virgifera virgifera* in Austria in 2004.

In neither of the two years were larvae detected, although beetles were found in emergence cages at the same and in nearby fields in 2004. Larvae, therefore, had definitely been present. Hpowever, they are probably not evenly distributed and the methods may not be sensitive enough to detect low populations. Investigations on egg and larval monitoring will be continued in future years.

Population development

Population growth from one year to the next can roughly be assessed by comparison of pheromone traps catches in the same area each year, in this case the region in northeastern Burgenland east of Lake Neusiedl called 'Seewinkel', the most eastern part of Austria on the borders to Slovakia and Hungary. The eastern part of this region is an intensive corn-growing area, to a large extent for seed-corn production, with many fields planted to continuous corn.

In 2002, the largest number of beetles caught per trap and week was 28, and more than 10 beetles were captured per week in 11 traps. In the next year, a maximum of 231 beetles was caught in one trap in one week; also, in 9 cases, >100 beetles were captured per trap per week. In 2004, the largest trap catch was 662 beetles in one week, which is probably around the maximum catching capability for this trap design; many traps were catching hundreds of beetles per week.

In 2004, different trap and pheromone replacement regimes were compared in a separate experiment, on a field of continuous corn in the village of Deutsch Jahrndorf (situated in this region at the confluence of the borders of Austria, Slovakia and Hungary). This is the area with, currently, the greatest WCR population in Austria. Monitoring was conducted from the end of June to the middle of October. Pheromone traps located on the four sides of a field

(1.5 ha; 500 × 300 m) were replaced every 1, 2, 3 and 4 weeks. If traps are left in the field for longer than a week, beetle catches fall rapidly, even after the second week (Figure 4).

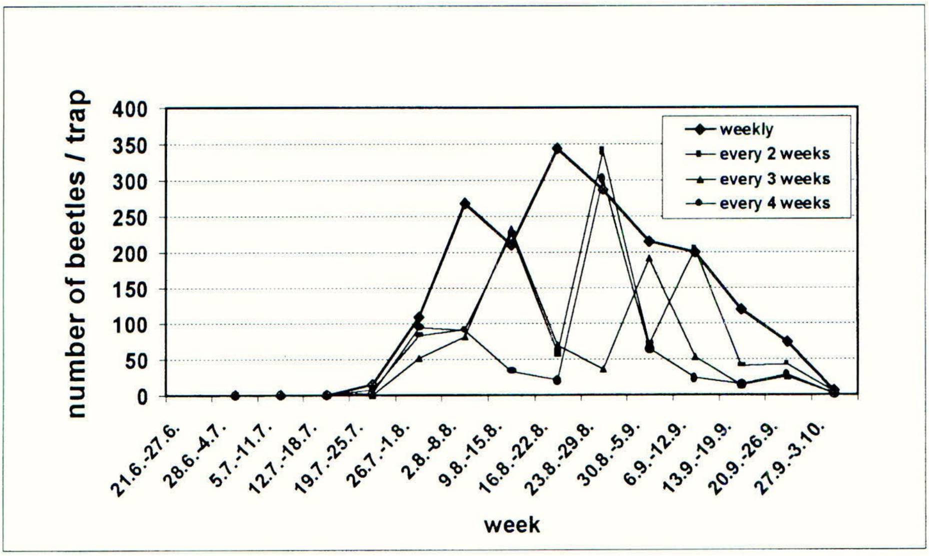

Figure 4. *Diabrotica virgifera virgifera* catches in different pheromone trap replacement regimes.

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Costs and benefits of European Community (EC) measures against an invasive alien species: current and future impacts of *Diabrotica virgifera virgifera* in England & Wales

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ABSTRACT

In Europe, the western corn rootworm (*Diabrotica virgifera virgifera*) is an invasive alien species that has been spreading since it was first discovered in the former Yugoslavia in 1992. It was detected in England for the first time in 2003. A Monte Carlo simulation model was used to predict spread and determine the annual maize area at risk over ten years. An economic analysis of the costs and benefits of the EC risk management measures, designed to eradicate or at least inhibit the spread of this maize pest, demonstrated that in England & Wales, their strict implementation does not appear to be economically justified, with management measures causing more losses than the potential damage caused by the beetle species itself. However, climate change scenarios indicate that raised summer temperatures will increase the area where maize can be grown and where western corn rootworm can complete its lifecycle, perhaps reaching more damaging population densities. Such a future scenario must be balanced with the impact of implementing strong action now against this invasive alien species.

INTRODUCTION

Western corn rootworm (WCR) (*Diabrotica virgifera virgifera*), is a univoltine oligophagous chrysomelid beetle from North America, where it is one of the two most serious pests of continuous grain maize (Oerke *et al.*, 1994). Larval root feeding is the primary cause of damage, reducing nutrient uptake and growth (Gavloski *et al.*, 1992). In the USA, the combined cost of soil insecticides that target larvae, aerial sprays that target adults and crop losses approaches $1,000 million annually (Krysan & Miller, 1986). WCR was originally detected in the former Yugoslavia in 1992, with severe damage first reported in 1996. In Serbia, yield losses can vary from 1% to 70%, although mean losses are around 30% (Sivcev & Tomasev, 2002). To protect maize within the European Union (EU) against the spread of WCR, the insect was added to the list of regulated pests in EC Plant Health legislation in January 1998 (Anon., 1998). Specific management measures for WCR include delay of harvest, use of insecticides and the restriction of growing maize within 1 km of an infested field for two years. Despite efforts to limit spread, by June 2003 WCR had been detected in five of the then 15 EU countries (EPPO, 2004). To determine whether the pest had entered England, species-specific pheromone traps were placed (in June 2003) in strategic positions identified as points of potential entry. WCR was subsequently detected for the first time on a pheromone trap in England in late August 2003 (Cannon *et al.*, 2005). Following the finding, a cost:benefit analysis was done to assess the impact of implementing EC management measures that aimed to limit the spread of WCR.

METHODS

In England, the vast majority of maize is grown for animal feed. This paper, therefore, concentrates on the impact of WCR and the EC measures on livestock farmers to manage the pest. Two alternative scenarios were envisaged and, using a stochastic Monte Carlo simulation model, annual estimates of costs associated with each scenario were made for a ten-year period.

The first model scenario

This model estimated costs resulting from yield losses in continuous maize as a consequence of not implementing EC measures. To estimate the losses, the maize area at risk had first to be determined. A risk analysis for the UK shows that annual variation in climate dramatically alters the area suitable for WCR establishment (MacLeod *et al.*, 2004). For example, in a cool year, sufficient heat is accumulated in only a small area to allow the development of a complete generation of WCR. By identifying the regions where maize is grown and overlaying them with climatic areas suitable for WCR development, the endangered area of maize (according to climatic conditions) can be determined as follows: 'cool' = 75 ha; 'typical' = 10,250 ha; 'warm' = 118,680 ha.

The model used the same areas to define a triangular probability distribution of the minimum, most likely and maximum annual maize area suitable for WCR development. Annual WCR spread rates from the initial sites of infestation were selected from a triangular distribution, with parameters based on spread reported in the literature. For example, spread through the monoculture corn belt of the USA occurred at a rate of from 44 to 125 km/year whilst increased landscape diversity slowed spread to 33 km/year (Onstad *et al.*, 2003). Baufeld & Enzian (2001) showed that without containment measures in place, spread of WCR in Europe was 60 to 100 km/year. Our model assumed that spread was a minimum of 60 km, most likely 80 km and a maximum of 100 km/year. The model combined the annual area suitable for WCR establishment with the annual rate of spread, and provided output in the form of maize area occupied by WCR each year over the next ten years. From 10,000 model iterations, the mean annual area occupied was used to calculate potential future losses in yield.

Evidence from European countries suggests that there is a time lag of approximately five years between the first finding of WCR and reports of economic damage in continuous maize (EPPO, 2003). Around 20% of maize in England & Wales is grown continuously and, hence, is potentially at risk from WCR. The model assumed yield losses would occur in 20% of the area occupied five years earlier, representing the time lag for WCR populations to grow, and that losses would vary: with a minimum of 10%, most likely 20% and a maximum of 30%.

The second model scenario

This model estimated the costs to maize growers of implementing the EC measures. The model was used again to randomize the annual area suitable for WCR establishment but used a slower rate of WCR spread. In Europe, with containment measures in place, WCR has spread at from 0 to 37 km/year (Baufeld & Enzian, 2001). Our model assumed WCR spread was limited to from 0 (minimum), through20 (most likely) to 40 (maximum) km/year. To account for the time value of money, future impacts were discounted to show the present value of impacts.

Under existing regulations, once a field is found to be infested with WCR, EC measures should be implemented in the field and all other surrounding maize fields within a 1 km Focus Zone. Measures are also required in an outer Safety Zone, extending from 1 to 6 km from the infested field. Cannon *et al.* (2005) describe in detail the EC measures applied in the Focus and Safety Zones in England & Wales during 2003/4. Defra commissioned farm consultants (ADAS) to conduct an economic analysis, to examine the effect of the imposition of restricted cropping on livestock farmers growing maize. ADAS identified seven categories of maize-growing holdings, and described how each may react to the imposition of statutory controls. Growers' response depended on many factors, including farm type, size and location, the management system and any physical, technical and financial constraints. The ADAS study considered groups of farmers likely to respond in a similar manner, and examined the effect of the rotational requirements on each group. In order to look at the likely cost to the whole industry, estimates of the numbers of growers and the area of maize grown were made for the most affected groups. Consideration was also given to the likely impacts of the CAP reforms and other industry influences. ADAS estimates were used in our stochastic model, and we assumed all infested maize fields were treated with insecticide costing £23/ha (€33/ha) per application. This cost was based on typical industry costs.

RESULTS

Costs of not implementing EC measures

Without implementing EC measures, on average, it would take three years for WCR to spread before stabilizing to occupy over 39,000 ha of maize each year (Table 1).

Table 1. Mean annual impact of *Diabrotica virgifera virgifera* on maize growers without implementing EC measures.

Year	Maize area infested (ha)	Continuous maize suffering yield losses (ha)	Value (£'000) of yield loss from	to	Discount factor	Present value (£'000) from	to
1	18,645	0	-	-	1.0000	-	-
2	36,390	0	-	-	0.9662	-	-
3	39,555	0	-	-	0.9426	-	-
4	39,504	0	-	-	0.9021	-	-
5	39,553	0	-	-	0.8717	-	-
6	39,491	3,729	260	312	0.8423	219	263
7	39,324	7,278	508	609	0.8139	414	496
8	39,167	7,911	553	663	0.7865	435	522
9	39,531	7,901	551	660	0.7601	419	502
10	39,094	7,911	555	666	0.7345	408	489
						1,895	2,272

Yield losses begin to be seen after five years, and the present value of aggregate losses after ten years ranges from £1.9 million to £2.3 million (Table 1).

Costs of implementing EC measures

ADAS (2004) concluded that 90% of maize growers in England would be able to accommodate the rotational requirements without any significant additional costs, but that livestock farmers, currently growing continuous maize with severe constraints to change, may incur additional costs averaging from £182/ha for fields in the Safety Zone to £243/ha for fields in the Focus Zone. Alternatives to growing maize considered by ADAS included growing grass, whole crop wheat or buying-in maize from a contract grower. Income from growing a cash crop on the released land, which could alleviate the additional costs, was not included because the farm equipment and management or technical expertise may not always be available.

Over a ten-year period of WCR spread, during which almost 7,200 ha will be holdings growing continuous maize with severe constraints to change, applying ADAS estimates of rotation costs plus costs of insecticide applications (to the mean of 10,000 model iterations), the impact of implementing EC measures on maize growers has a present value of approximately £14.7 million (Table 2). No yield losses are incurred under the statutory campaign, since populations of WCR are prevented from reaching damaging levels.

Table 2. The present value of economic impacts to maize growers having to spray against *Diabrotica virgifera virgifera* and those likely to have severe constraints in changing rotation from continuous maize.

Year	Maize occupied (ha)	Spray costs (£'000)	Maize severely affected (ha)	Rotation costs in severe area (£'000)	Discount factor	Present value industry costs (£'000)
1	100	5	100	19	1.000	24
2	5,015	231	2,227	426	0.9662	643
3	8,936	411	3,712	710	0.9426	1,080
4	13,608	626	3,848	736	0.9021	1,290
5	17,912	824	4,483	857	0.8717	1,571
6	22,119	1,017	4,724	903	0.8423	1,778
7	24,590	1,131	5,030	961	0.8139	1,913
8	25,759	1,185	5,608	1,072	0.7865	2,028
9	26,411	1,215	6,158	1,177	0.7601	2,110
10	26,528	1,220	7,176	1,372	0.7345	2,228
						14,664

Cost : benefit analysis

Summing industry costs of implementing EC measures for the next 10 years, and comparing them with expected losses as a result of living with WCR, the cost : benefit ratios range from 14.7 : 1.9 to 14.7 : 2.3, approximately 1.0 : 0.13 to 1.0 : 0.16, indicating that based on the assumptions used in the model, there does not appear to be an economic justification for implementing the measures against WCR in England.

CONCLUSIONS

The stochastic model used to estimate the costs and benefits of implementing EC WCR control measures in England & Wales shows that strict implementation of the measures does not appear to be economically justified over the next ten years. Management measures, especially the prohibition of growing maize in demarcated zones, can impose substantial costs on maize growers who have severe constraints to change. In contrast, with no statutory measures in place, yield losses caused by WCR in continuous maize are likely to be significantly lower than the cost of measures resulting from forced rotation.

Costs resulting from a forced change in rotation are potentially substantial for some growers and whilst it is acknowledged that assessing the cost of a change in rotation is difficult (Baufeld, 2003) and thus not included amongst the costs of impacts considered by the EU *Diabrotica* project by Vidal (2003), not including such costs can seriously underestimate the impact of management measures on maize growers.

This analysis has assumed that the area of maize grown in England remains stable. With reform to the Common Agricultural Policy, low-temperature-tolerant maize cultivars and increasingly warmer summers due to climate change, it is likely that the area of maize will increase. If so, the proportion of continuous maize would probably expand. Under the UK CIP02 climate-change scenario, large areas of England will become suitable for WCR by 2050 (Baker *et al.*, 2000); with an increased maize area, this would increase the area at risk and potentially increase industry-wide yield losses from WCR. Further work is necessary to assess whether the cost : benefit ratio is likely to change sufficiently, such that it would make economic sense to apply the EC measures now to avoid future losses under such a scenario of climate change.

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Initial movements of the introduced alien western corn rootworm (*Diabrotica virgifera virgifera*) for colonising suitable habitats

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ABSTRACT

In the late 1980s, a new maize pest, western corn rootworm (WCR) (*Diabrotica virgifera virgifera*), was accidentally introduced from North America into Serbia. Within 10 years, this alien beetle spread rapidly throughout Central Europe. Recently, several new sites of isolated introductions were reported in Europe, such as around Paris (France), Basel (France and Switzerland), Amsterdam (the Netherlands) and London (UK). These multiple introductions raise the question of the process of initial spread of the beetles over unfavourable habitats, with movement towards maize fields being one of the potential key factors behind the invasiveness of WCR. In order to investigate such initial colonisation movements of WCR adults, in southern Hungary in 2003 and 2004, mark release/recapture techniques were applied in large steppe and lucerne areas. Preliminary results underline that WCR is a very active flyer, and is able to move actively over long distances; however, no consistent major vectors of directed flight were found. Circular correlations were shown between WCR movement and habitat structures, such as maize and lucerne.

INTRODUCTION

In the late 1980s, a new maize pest was accidentally introduced from North America into Serbia (Baca 1994). This invasive pest, the western corn rootworm (WCR) (*Diabrotica virgifera virgifera*) (Coleoptera: Chrysomelidae) is a univoltine maize herbivore, with eggs overwintering in the soil of maize fields, larvae feeding on maize roots, and adults feeding on maize leafs or silk (Chiang, 1973). Most damage is caused by the root-destroying larvae, resulting in plant lodging. In Europe, the large-scale spread of WCR varies much between years and regions, reaching 60 to 100 km per year (Edwards *et al.*, 1999; Baufeld & Enzian, 2005). Within 10 years, this invasive beetle has spread rapidly throughout Central Europe (Kiss *et al.*, 2005). Recently, several new sites of isolated invasions were reported in Europe, such as around Paris (France), Basel (France and Switzerland), Amsterdam (the Netherlands) and London (UK) (Kiss *et al.*, 2005). These multiple introductions raise the question of the process of the initial movements of the beetle over non-native habitats for colonising maize fields as one of the potential key factors behind the invasiveness of WCR (Drake *et al.*, 1989; Wittenberg, 2005).

Processes of introduction are usually divided into entry, the period of adaptation and establishment, and large-scale spread (Wittenberg & Cock, 2001). A successful adaptation period and establishment is depending on (a) the ability to colonise suitable habitats or hosts, (b) a small minimum viable population size, (c) the fitting of climate parameters, and (d) a high intrinsic rate of increase, as is known from many classical biological control cases in weeds (Wittenberg & Cock, 2001; Wittenberg, 2005). After entry and establishment, the successful spread and development of large populations, as well as the likelihood of economic and environmental impacts, can be summarised (a) in reproductive mechanisms, (b) in dispersal mechanisms, (c) in a tolerance of environmental factors, (d) in a low mortality, owing to the low impact of indigenous natural enemies (Toepfer & Kuhlmann, 2005), and (e) in the availability of suitable hosts or food webs (Wittenberg, 2005).

In this study we aimed to investigate the colonisation process of small populations of this alien pest, from the site of introduction towards suitable habitats (such as maize), by applying mark release/recaptures techniques.

MATERIAL AND METHODS

In order to investigate initial colonisation movements of WCR adults from unfavourable areas into maize fields, mark release/recapture techniques were applied. In southern Hungary in 2003 and 2004, two non-maize areas were chosen as release areas for marked beetles: namely, an 80-ha steppe and a 60-ha lucerne field. In each area, two maize plots of 10 × 10 m were established 300 m away from a central release point. Further, all non-crop and crop habitats were recorded over longer distances around the release points. About 6,000 beetles were marked with orange, yellow or pink fluorescence powders (Radiant Color, BE and Fiesta Colours Swada, UK) and released in each of 5 releases in two years, respectively, giving a total of 60,000 released beetles. For recapturing beetles, non-baited yellow sticky traps (Pherocon AM, Trece Inc., USA), were placed in four circles (30, 100, 200, 300 m) around the central release point, totalling > 500 traps in each of the two study areas. In addition, 16 transparent sticky pheromone traps were placed (PAL traps with a lure of the females' sex pheromone Recemic 8-methyl-2-decyl propanoate: Toth *et al.*, 2003) in circles of 1,000, 1,500, 2,000, 2,500 and 3,500 m. All traps were changed before each release. Every second day, beetles were recovered from the traps and their 'vectors of movement' were recorded, i.e. distance and direction (geo-referenced by GPS, Garmin, USA). Mean vectors of movement were analysed for their concentration by the Raleigh Test, and circular-circular or circular-linear correlations were applied, to analyse the factors behind the movement directions (Batschelet, 1981; Services, 2004).

RESULTS AND DISCUSSION

WCR actively spread over more than 100 ha of non-maize areas, and a few marked beetles were even found up to 2,500 m from the release point. This underlines the known phenomena that WCR is a very active flyer and is able, actively, to overcome longer distances (Onstad *et al.*, 1999; Spencer *et al.*, 1999). However, no consistent major vectors of directed movements were found, as only 4 mean vectors out of 10 were concentrated ($P < 0.005$, Raleigh test), meaning most movements of the released populations appeared to be non-directed.

Preliminary results of circular correlations revealed that the few concentrated movements of the released WCR populations were slightly directed towards maize fields within 1,500 m distance around the release point ($P = 0.014$, $t = 2.5$, d.f. 116). However, no significant correlations were found with the two (300-m distant) maize plots, suggesting that more-distant maize fields were also influencing beetle movements. A directed movement of the released WCR adults was proven towards flowering lucerne fields ($P = 0.006$, $t = 2.9$, d.f. 45), but not towards sunflower fields ($P > 0.05$, d.f. 142). However, marked beetles were found in nearly every flowering habitat, and it is suggested that introduced adults in non-maize areas will find and feed on pollen of many plants (Moeser & Hibbard 2005). This is probably also the reason why only about 3.7 % (s.d. 4.3 %) of the spreading beetles in this study colonised the 300-m distant maize plots.

In conclusion, accidentally introduced WCR will probably find and use many different flowering plants as a food source, and may find maize fields for oviposition as a second step.

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