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REVIEW

Integrated fly management in European ruminant operations from the perspective of directive 2009/128/EC on sustainable use of pesticides

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Abstract Integrated pest management (IPM) in agriculture animals remains undeveloped as compared to IPM in crops. With respect to the range of external nuisance arthropods that may bother farm animals, development and implementation of systematic IPM strategies are difficult to carry out. However, recurrent outbreaks of blue tongue disease in sheep and cattle, the public threats regarding the prophylactic use of veterinary insecticides and the need to preserve the efficacy of available actives have to lead the reflexion on new control strategies for arthropod pests of livestock. A recent extension of EU regulation on the use of pesticides in crops provides an opportunity to compare IPM strategies and to suggest new lines of reflection for the control of nuisance pests in ruminants under European conditions. In this paper, actions suggested by the Annex III of the Directive 2009/128/CE on Sustainable Use of Pesticides and related National Action Plans from 28 member states of the EU were reviewed from an animal production perspective by a group of veterinary entomologists. Eight lines of action have been identified and thus challenged with respect to current husbandry practices in modern European ruminant operations. Many IPM strategies for crops were identified to be unsuitable for large animals. Suggestions for implementing tools, opportunities and constraint assessment, and needs for support were also discussed. Only control of pest development sites and monitoring of harmful organisms were considered achievable in the near future; both in conjunction with the use of topical insecticides. Complementary actions such as alternatives to chemical control require further researches and industrial development. Marketing of IGR-based feed additives would be of great interest, but development of new compounds for veterinary medicines is very unlikely with respect to the European regulatory environment and associated cost of development.

Keywords Integrated pest management · Veterinary medicine · Flies · Insecticides

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Introduction

The sustainability of pest control is frequently compromised by two processes: (1) the appearance of new pest species and (2) the emergence of new resistance patterns of indigenous organisms. These mechanisms have frequently led to the loss of valuable chemicals and uncontrollable pest and disease outbreaks which can be amplified by environmental changes (climatic or local, through landscape fragmentation or irrigation for example) and socio-demographic changes (chaotic urbanisation, poverty, degradation of the medical and veterinary health services, and globalisation of commercial exchanges, to name but a few) (Gubler 2002; Purse et al. 2005).

Under current EU regulation, only compounds enlisted in Annex I of Commission Regulation (EU) No. 37/2010 on classification of the pharmacologically active substances regarding maximum residue limits (MRL) in foodstuffs of animal origin are allowed for use as veterinary medicines. Thus, only a few drugs are granted a marketing authorization for use as insecticidal/acaricidal medicines in ruminants in the EU. Synthetic pyrethroids (SPs) are the most used compounds (permethrin, cypermethrin, deltamethrin, and flumethrin). Identification of new compounds and development of new medicines for farm animals that comply with the high European standards could take years or even decades to develop and is probably cost prohibitive. Therefore, extending the efficiency of existing molecules against endemic pest arthropods of livestock or even emerging species must be preserved for as long as possible.

In 2008, the unexpected outbreak of Blue Tongue virus (BTV) in Europe has highlighted the limits of massive use of topical insecticidal medicines in ruminants from an economical as well as a social point of view. Several works demonstrated the relatively low efficacy of the deltamethrin-based products on several *Culicoides* spp. midges (Schmahl et al. 2008; Mehlhorn et al. 2008a, b; Schmahl et al. 2009; Mullens et al. 2010; Venail et al. 2011), and threats regarding the consequences of approximately monthly application of SP on cattle and sheep on wild fauna and beneficial species such as honeybees are rising. Opponents to systematic disinsectization of farm animals pointed out that no product available on the European market was registered for the control of midges (off-label use). The European Food Safety Agency (EFSA) issued recommendations for a parsimonious use of SP, in order to mitigate environmental impact of mass disinsectization (Algers et al. 2008). Risk of insecticide resistance emergence in *Culicoides* spp. was also discussed. Bluetongue virus (Wilson and Mellor 2008) and more recently Schmallenberg virus (SBV) (Hoffmann et al. 2012) were spread in northern Europe by midges species for which there was scant data on habits. Studies indicated that the treatment of livestock and animal housing with SP, the use of midge-proofed stabling for viremic or high-value animals, and the promotion of good farm practice in order to at least partially eliminate local breeding sites were the best options available at this time (Carpenter et al. 2008), at least before a vaccine became available in the case of BTV (Savini et al. 2008). Treatment of animals is certainly the less acceptable method within European public opinion.

In 2009, the European Parliament and the Council of the European Union issued the Directive 2009/128/EC for the Sustainable Use of Pesticides (DirSU) to reduce the risks and impacts of pesticide use on people's health and the environment (OJEC 2009). Topical insecticidal medicines for ruminants are not within the scope of the DirSU. Products for building disinsectization, which can be considered as key elements of pest arthropod control programs, are ruled by the EU Regulation No. 528/2012 on biocides (OJEC 2012), but it is anticipated that the scope of the DirSU will be extended to cover biocidal products.

The DirSU features the principle of integrated pest management (IPM). Article 3–3 of the DirSU indicates that IPM would be "the careful consideration of all available [plant] control techniques, and subsequent integration of appropriate measures, that discourage the development of populations of harmful organisms and keep the use of [plant] protection products and other interventions at levels that are economically and ecologically justified and reduce or minimize risks to human health and the environment. IPM emphasizes the growth of a healthy [crop] with the least possible disruption to [agro-ecosystems] and encourages natural pest control mechanisms". The scope of this definition is clearly crop protection, and European pesticide regulation displays significant differences with regulation on veterinary medicinal products. However, authors have estimated that compliance to the Directive 2009/128/EC could be a fruitful attitude in order to provide pragmatic and achievable recommendations for implementing IPM strategies in livestock operations.

The objective of this paper is to present the potential of existing scientific research as well as existing expertise and knowledge in light of the DirSU to support the stakeholders in their political and technical decisions concerning management of food producing animal risks related to insecticide use and the environment.

Materials and methods

Directive 2009/128/EC

The full text of this directive is available on the website of the Official Journal of the European Union (http://eur-lex.europa.eu/) in all official languages of the EU. This text has been adopted on 21 October 2009 and published on 24 November 2009 (OJEC L309) and came into force the following day. The directive was expected to be transposed and implemented by Member States (MS) by 25 November 2011. One of the key features of the directive is that each MS should develop and adopt its *National Action Plan* (NAPs) and set up quantitative objectives, targets, measures, and times to fulfil the directive's provisions. MS had until 14 December 2012 to communicate their NAPs to the European Commission and to other MS.

Annexes of the directive

Four annexes have been attached to the DirSU. Annex III entitled "General principles of integrated pest management" was used as guideline for the present work. Regulators stated that measures designed to amend non-essential elements of this directive in order to take account of scientific and technical progress shall be adopted later, in accordance with regulatory procedures. At the time of writing, no new provisions had been issued. DirSU has been issued for promoting the sustainable use of pesticides in crops. All proposals refer to crop protection and plant protection measures and products. Some of the measures are clearly not applicable to animal protection and they have been withdrawn; withdrawal of these actions is however discussed in the discussion section. Where applicable, wording of provisions has been changed in order to encompass agriculture animal protection, i.e., in turning crop into livestock, or plant protection measures into livestock protection measures.

National action plans

Member states were encouraged to make public drafts of the NAPs as well as to encourage public participation in respect of the drawing up of certain plans and programs related to the environment. Therefore, 28 NAPs are available online and they can be compared (http://ec.europa.eu/food/plant/pesticides/sustainable_use_pesticides/national_action_plans_en.htm).

All available NAPs were examined for this work. Special attention has been paid to chapters dedicated to IPM. As already exposed, actions exclusively related to crops have been withdrawn. When recommended measures were appropriate for both crops and agriculture animals, a common wording was proposed without reference to any Reign. When appropriate, the words crop or plant were changed into animals or livestock.

IPM in livestock: Proposals

Generic measures from Annex III of the DIRSU

Annex III of the DirSU provides eight tracks for reflection upon IPM implementation which are suggested to be followed by MS. The suggested scope of actions encompass the prevention/suppression of harmful organisms by choosing options other than pesticide use, the monitoring of harmful organisms by adequate methods and tools, the development of robust and scientifically-based decision making schemes, the promotion of methods other than chemical ones if they provide satisfactory pest control, the promotion of targeted treatment of pests with specific pesticides, the use of pesticides at the necessary levels, the implementation of anti-resistance strategies to maintain effectiveness of the products, and the success assessment of applied animal protection measures.

Initial official provisions of Annex III of the DirSU are collated in Table 1. Three proposals related to crop rotation,

Table 1 Main provisions of the Annex III of the Directive 2009/128/EC and proposed wording for agriculture animals

	Initial wording according to DIRSU Annex III	Final wording
1	The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:	The prevention and/or suppression of harmful organisms should be achieved or supported among other options especially by:
	–crop rotation	–*withdrawn*
	–use of adequate cultivation techniques (e.g., stale seedbed technique, sowing dates and densities, under-sowing, conservation tillage, pruning, and direct sowing)	–use of adequate husbandry techniques, including building design, manure and waste management, animal density management
	–use, where appropriate, of resistant/tolerant cultivars and standard/certified seed and planting material	–use, where appropriate, of resistant/tolerant breeds
	–use of balanced fertilisation, liming and irrigation/drainage practices	–adequate management of pastures and building surroundings, including drainage of moistly area, tree cutting down, etc.
	–preventing the spreading of harmful organisms by hygiene measures (e.g., by regular cleansing of machinery and equipment)	–preventing the spreading of harmful organisms by hygiene measures (e.g., by regular cleansing of building and facilities),
	–protection and enhancement of important beneficial organisms, e.g., by adequate plant protection measures or the utilisation of ecological infrastructures inside and outside production sites.	–*Parasitoides*
2	Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.	Harmful organisms must be monitored by adequate methods and tools, where available. Such adequate tools should include observations in the field as well as scientifically sound warning, forecasting and early diagnosis systems, where feasible, as well as the use of advice from professionally qualified advisors.
3	Based on the results of the monitoring the professional user has to decide whether and when to apply plant protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms threshold levels defined for the region, specific areas, crops, and particular climatic conditions must be taken into	Based on the results of the monitoring the professional user has to decide whether and when to apply livestock protection measures. Robust and scientifically sound threshold values are essential components for decision making. For harmful organisms threshold levels defined for the region, specific areas, animal hosts, and particular climatic conditions must be taken into

Table 1 (continued)

	Initial wording according to DIRSU Annex III	Final wording
	account before treatments, where feasible.	account before treatments, where feasible.
4	Sustainable biological, physical, and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.	Sustainable biological, physical, and other non-chemical methods must be preferred to chemical methods if they provide satisfactory pest control.
5	The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, non-target organisms, and the environment	The pesticides applied shall be as specific as possible for the target and shall have the least side effects on human health, on farm animal health, non-target organisms, and the environment
6	The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g., by reduced doses, reduced application frequency or partial applications, considering that the level of risk in vegetation is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.	The professional user should keep the use of pesticides and other forms of intervention to levels that are necessary, e.g., by reduced doses, reduced application frequency or partial applications, considering that the level of risk in livestock is acceptable and they do not increase the risk for development of resistance in populations of harmful organisms.
7	Where the risk of resistance against a plant protection measure is known and where the level of harmful organisms requires repeated application of pesticides to the crops, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.	Where the risk of resistance against livestock protection measures is known and where the level of harmful organisms requires repeated application of pesticides to the animals, available anti-resistance strategies should be applied to maintain the effectiveness of the products. This may include the use of multiple pesticides with different modes of action.
8	Based on the records on the use of pesticides and on the monitoring of harmful organisms, the professional user should check the success of the applied plant protection measures.	Based on the records on the use of pesticides and on the monitoring of harmful organisms, the professional user should check the success of the applied livestock protection measures.

use of tolerant/resistant cultivars, and enhancement of beneficial organisms have been considered as too far from strategies applicable to farm animal IPM. Thus, they have been withdrawn from the initial text.

Two proposals have been significantly changed: adequate cultivation technique turned into adequate husbandry technique; balanced fertilization, liming, and irrigation/drainage turned into adequate pasture and building management. Only minor changes were made in other proposals.

Detailed measures from NAPs

From Annex III provisions, NAPs focus on some aspects or others, depending on local conditions. The initial eight tracks of reflection are more or less substantiated. Eleven recommended detailed measures were identified in the 28 NAPs; they are reported in Table 2. In depth analysis of NAPs also provide some interesting suggestions on tools and methodologies needed for the implementation of IPM. Strengths, weaknesses, and support requirements of such proposals are also indicated in Table 2. Practical implementation of such measures is discussed in the following section. As initial measures were intended for IPM implementation in crops, wording of measures has been adapted to livestock production, as already described.

Discussion

Withdrawn items

Annex III clearly indicates that crop rotation, use of tolerant/resistant cultivar, and enhancement of beneficial organisms are options that must be considered. A change in the food animal species produced cannot generally be considered as most pest flies are parasites of several agriculture animal species. Interest of resistant animal hosts such as tick-resistant *Bos taurus* × *Bos indicus* cross breed or trypanotolerant cattle both resistant to trypanosomes and ticks has been substantiated for some tropical areas (Mattioli et al. 2000; Bouyer et al. 2013). However, such an evolution would imply dramatic genetic changes in highly productive European cattle breeds and no data support the interest of this technique for increasing resistance to nuisance arthropods other than ticks. Beneficial organisms have been identified as predators (mainly parasitoides) or parasites (mainly fungi) of arthropod pests of livestock such as ticks, tsetse or *Stomoxys calcitrans* (Linnaeus, 1758) (Bouyer et al. 2011b; Samish 2006; Kaaya and Munyinyi 1995), but the effects remained small-scaled and temporary.

Prevention and suppression of harmful organisms

It has been demonstrated that *S. calcitrans* pupae may develop in round hay balls as well as in wasted hay felt from feeders (Broce et al. 2005; Talley et al. 2009). Therefore, feeders should be situated on firm, dry places where food stuff and animal manure would be easy to remove. Drainage of such places would facilitate maintenance. Roughly speaking, all places that do not naturally dry off during summer should

Table 2 Main actions to be carried out for the implementation of IPM in farm animal operations with respect to Annex III of the Directive 2009/128/EC and suggestions for implementing tools, expected opportunities and constraints, and needs for support

Refer to Annex III	Actions	Tools	Opportunity	Constraints	Support needed for
1. Prevention and/or suppression of harmful organisms	Husbandry techniques Building design	Inventory/guidelines	Limit nuisance from arthropod pest	Not always applicable, depends on farm organization, facilities	Demo trails, on site assistance
	Pasture and building surroundings management	Guidelines Edges maintenance drainage	Controlling development sites and outdoor sources	Workload	Training, demo trails, on site assistance
	Hygiene measures	Minimum recommendations for animal and pest specific hygiene	Alternative to insecticide	Time consuming	Training and advisory services
	Desinsectization of buildings	Minimum recommendations for buildings treatment	Easy to implement	Selection of molecules different from epicutaneous treatment	
2. Monitoring harmful organisms	Regular observations in the field/on animals (scouting)	Checklists, observation sheet, software	Avoid useless treatments improve farmer competence	Requires expertise to be built in time, high level advisory services	Training, on site assistance
	Warning, forecasting, and early diagnosis	Public monitoring system at regional or national level Monitoring device/population dynamics modeling	Avoid useless treatments, Improve efficacy	Requires expertise to be built over time, high level of advisory, investment in detection devices.	Training, on site assistance, model development at proper scale, information platform available (website)
3. Application of animal protection measures (APM)	Threshold as application criteria	Management decision support tools (e.g., leaflets with decision schemes, recommendation, software.)	Avoid non beneficial treatments	Requires expertise to be built over time, high level of advisory services, Risk of animal losses	Training, on site assistance, threshold definition at proper scale, Information platform available
4. Sustainable biological, physical, and other non-chemical methods	Alternative to chemical control	Guidance on the alternative control means and their efficiency	Avoid treatments when valid alternative available	Application not providing satisfactory pest control	Training, on site assistance
	Development of the sterile insect technique to control vectors	Area-wide IPM principles and methods	Validated alternative to insecticides	Area-wide organization necessary	National/agency-based organisation of the control
5. The Animal Protection Product (APP) applied shall be as specific as possible	Select APP efficacious to the pests present	Guidelines on APP category to be used and on mitigation measures to reduce risk	Increase efficacy on pest control by precise applications	Limited spectrum of action for the selected products	Training, on site assistance
6. Use of pesticides at necessary levels	Apply doses and application frequency included on the label	Information campaign on the need to respect the label	Cost reduction, development of good practice management	Possible resistance Development due to under dosing	Training, on site assistance
	Restrict treatment to activity period of vectors	Information on vector activity available to public	Reduction of insecticides use	Development of reliable population dynamics models	Information platform available (website)
	Restrict treatment to vectors' biting sites	Footbaths/restricted application	Easy to implement Reduced impact on non-target organisms	To be tested for European vectors	Guidelines for using restricted application, Training, on site assistance

drain off in order to control development sites: This strategy has been efficiently combined with chemical techniques within an integrated strategy in Reunion Island (Bouyer et al. 2011b). Manure can also be covered with black plastic which increases the temperature inside the pile, destroying *S. calcitrans* larvae. Finally, the use of a manure pit is also very efficient to reduce the availability of breeding sites, not only for *S. calcitrans*, but also for biting midges (Ninio et al. 2011).

In tropical areas, large trees are suitable resting site for sand flies (Oca-Aguilar et al. 2013), and *S. calcitrans* and *Musca* spp. tend to prefer locations with forestry surrounding (Leclercq 1971; Rouet 2011), as well as tabanids which live outdoors and rest on trees. Trees are often used as wind-breaker hedges, quite close to farm buildings. Giant gramineae with large leaves such as sugar cane or elephant grass offer suitable resting sites for *S. calcitrans* (Gilles and David 2007). Identification of resting sites for main pests could improve the control strategies of limiting suitable surfaces or spraying them specifically with residual insecticides. *S. calcitrans* has been observed to preferably rest outdoors on south and east-facing bright surfaces of barns and fences, whereas *Musca domestica* (Linnaeus, 1758) tends to rest indoors (Rouet 2011; Lysyk 1993). Resting surfaces could also be painted black using insecticidal paints, a strategy that proved very efficient to control *Culex quinquefasciatus* (Say, 1823) and the pan-tropical urban pest mosquito *Anopheles gambiae* (Gilles, 1902), the main malaria vector in Sub-Saharan Africa (Mosqueira et al. 2010a, b). An alternative strategy could be the interception of *S. calcitrans* between their hunting and resting sites using insecticide-impregnated nets (Maia et al. 2010; Bauer et al. 2006) or even to protect the breeding sites (manure stocks) with such nets to intercept females before they lay their eggs, and unfed emerging adults (which are more sensitive to insecticides).

When applied, insecticides of different classes should be sprayed on animals and on building walls and roofs or insecticide-impregnated nets.

Monitoring of harmful organisms

Monitoring is important strategically in providing early warning of problems that may arise and is widely considered as a necessary component of any IPM strategy (Vreysen et al. 2013; Gerry et al. 2011; Ehler 2006) in order to correctly identify the harmful organisms whose physiological and ecological needs may vary amongst each other. Pest insects may be caught by means of various traps and any increase in the number of captures may indicate a change in the relative abundance of a given species or the emergence of a seasonal species.

Regarding anthropophilic or zoophilic species such as *S. calcitrans* and *Musca* spp., large scale entomological surveillance (ES) is of limited interest. Geographical range of such species is very large and seasonal recolonization of farms

Table 2 (continued)

Refer to Annex III	Actions	Tools	Opportunity	Constraints	Support needed for
7. Anti-resistance strategies should be applied to maintain the effectiveness of the products	Use of multiple APP with different modes of action	Regional or national anti/resistance strategy with simple recommendations for farmers, based on international guidelines	Maintain product efficacy and hence optimal pest control	Reduced product availability due to authorization restrictions	Training, on site assistance Development of new molecules/biocides
8. Check the success of the applied livestock protection measures	Maintain records on pesticide use and on the monitoring of harmful organisms	Recommendations	Progressively implement sustainable use, capitalize experience	Higher workload	Direct and indirect checking and recording, to reward system in place

comes from local on-farm sources or from the close neighborhood (Beresford and Sutcliffe 2009). In Europe, even in northern latitudes, eradication of the nuisance fly population never happens; a new generation emerges in spring from pupae that has survived in larval resting sites for diapausing species (*Musca autumnalis* (De Geer, 1776)) or development cycles can be slowed down until better climatic conditions and some imago can be observed during winter (*S. calcitrans*).

Various devices have been developed for pest insect monitoring in crops or greenhouses and vectors in pastures (Baldacchino et al. 2013). They most often focus on a single nuisance species and an attractant can be used for increasing sensitivity of detection devices (Baldacchino et al. 2014). The most reliable way to identify emergence of pest arthropods in livestock would certainly be to carefully observe the animals at different times of the day. Flies can be counted on cattle's forelegs (*S. calcitrans*) or other body parts (head and back). Assessment of fly-repelling behaviors may also be an option to consider (Gerry 2007; Vitela et al. 2007). This activity is really time consuming as several animals must be observed, and the observer must be able to identify the different species of flies. Thus, the use of monitoring traps is often a more appealing approach. Some difficulties immediately arise from the use of insect traps in cattle or sheep operations. First of all, animals are frequently outdoors during summertime and therefore monitoring systems have to move with them in large open spaces. It is also important to ensure traps are protected from curious animals. Many different insects can be caught in traps including beneficial species and even small vertebrates. However, specific traps are needed for some major pests of cattle that can be observed on animals only (*Haematobia irritans* (Linnaeus, 1758)). In barns, traps must also be protected from animals, especially cattle. Effectiveness of traps made of phthalogen blue clothes (Vavoua, Nzi) (Gilles et al. 2008) as well as various sticky traps (Gilles et al. 2008; Taylor and Berkebile 2006; Berry et al. 1986; Beresford and Sutcliffe 2012; Cilek 2003; Hogsette 1993) or even solar-charged, battery-powered, or electrocuting grids (Pickens 1991) have been tested for *S. calcitrans*. Blacklight suction traps are extensively used for monitoring of *Culicoides* species in farm animal operations (Viennet et al. 2011, 2012). Disposable sticky traps seem to be a more practical device to implement on farms for monitoring relative fly abundance in commercial cattle farms. Sticky ribbons or cardboard can be changed on a regular basis (monthly in winter or weekly in summer), and the number of caught organisms can be recorded. Glue-coated string is another solution that can allow monitoring of endophageous vectors within buildings (Bouyer et al. 2011b). Stuck flies can be counted per meter and per day each week on a given length of rolled-out clear string.

Interest of ES of pest insects or arthropod vectors of public health interest has been substantiated a long time ago (Serfling 1952). Monitoring pests can allow restricting chemical treatments to activity periods. Management of large scale ES of arthropod pests of livestock population dynamics can be implemented in most of European countries, provided that public authorities make this decision. Such ES has been implemented for the follow up of the eradication of warble fly and it is currently running for midges, regarded as vectors of BTV (Goffredo et al. 2004; Goffredo and Meiswinkel 2004; Ivana et al. 2009; Lacková et al. 2009; Ramilo et al. 2012).

Application of animal protection measures (APM)

In any pest management approach, the pest's population level should guide management decisions such as when and how to control the pest (Gerry 2007). Many authors have issued high quality results on correlation between fly burden and economic losses (Campbell and Berry 1987; Campbell et al. 2001; Taylor et al. 2012a; Catangui et al. 1997). Generalization of these results remains difficult. Therefore, action thresholds for the application of insecticides on animals or any other control measure do not currently exist in Europe. The first observation of flies on animals in conjunction with positive fly trapping would be the signal to initiate control measures (threshold). In the case of *S. calcitrans*, applying early treatments before populations peak is recommended and seems to delay the apparition of high densities and reduce peak density (Bouyer et al. 2011b).

Sustainable non chemical methods of control

In confined cattle, fences can be defended by insecticide-treated nets (ITNs). Authors have tested ITNs for preventing cattle being bitten by *Culicoides* midges (Bauer et al. 2012; Del Río et al. 2014). Three meter high nets surrounding the area to be defended were required to significantly decrease the midge population abundance. This strategy is also efficient against *Stomoxys* with 1 m-high fences (Maia et al. 2010; Bauer et al. 2006). Impact on non-targeted organisms has to be considered (Del Río et al. 2014). The use of photovoltaic cells has recently be proposed in order to attract polarotactic species such as tabanids, and thus destroy them using an associated electric powered device (Blahó et al. 2012). Such self-sufficient traps could be used in pastures to prevent attacks from heavy insects that are less sensitive to low doses of SPs that are generally approved for use in agriculture animals.

Practical use of pest arthropod predators remains a field to investigate. However, many works have been published on parasitoids of nuisance flies. In Europe, synanthropic flies are exposed to at least 41 species of parasitic Coleoptera and Hymenoptera. *Muscidifurax* and *Spalania* species are really effective against harassing flies of livestock. *Spalangia cameroni* may have a high potential for the control of *S. calcitrans* (Baldacchino et al. 2013) and could be an alternative to chemical control of *M. domestica* (Skovgård and Nachman 2004), but the control cost is often prohibitive if governmental or professional organizations are not involved to produce the parasitoids. In the USA, several companies are now able to provide these ancillary insects for on-farm use. Biological control needs sustained releases of parasitoids and moderate to high control costs must be considered. Moreover, introduction in a given biotope of exotic selected species of parasitoids should certainly be avoided.

Since the early 1990s, bacteria *Bacillus thuringiensis israelensis* (Bti) or *Bacillus sphaericus has* have been used successfully in the biological control of mosquitoes within large areas in Germany (Becker 1997). *Bacillus thuringiensis israelensis* produce so-called d-endotoxins that are specifically toxic to some insect species. Recently, Australian authors have tested toxicity of various strains of Bti to buffalo fly (*H. irritans exigua* (de Meijere, 1906)), sheep blowfly (*Lucillia cuprina* (Wiedemann, 1830)), and sheep louse (*Bovicola bovis* (Haeckel, 1896)) and found that some isolates have a high toxic activity against larvae of the two fly species and a moderate activity against lice (Gough et al. 2002).

The main alternative biological control method that is available presently is the sterile insect technique (SIT), that allowed the eradication of screwworms (*Cochliomyia hominivorax* (Coquerel, 1858)) from northern and central America (Wyss 2000), and more recently from Libya following an outbreak caused by the importation of infested cattle from southern America (Vargas-Terán et al. 1994). The SIT technique consists of releasing male insects that are either sterilized using ionizing radiation (Dyck et al. 2005) or transformed to carry a lethal gene (Alphey 2014). It is considered that SIT might represent a major alternative for controlling mosquito vectors (McGraw and O'Neill 2013). Recently, it was proposed to use sterile males as specific transporters of biocides like juvenile growth hormone analogues instead of sexual competitors only, a technique known as boosted-SIT (Bouyer and Lefrançois 2014).

Specific treatments for the target organisms

Only a few drugs are available for use as veterinary medicines in Europe. Beside SPs are the formamidin compounds (amitraz) which is recommended for the control of mange mites, lice, ticks, and sheep keds, organophosphates (dimpylate) with the same indications and pyrimidin derived compounds (dicyclanil) for blowfly control. Four macrocyclic lactones are also available in Europe, without respect to their larvicide activity on internal myasis (*Hypoderma* spp., *Oestrus ovis* (Linnaeus, 1758)), they are active on lice and mange mites, and their topical formulations are authorized for the control of *H. irritans*. There was some evidence recently that ivermectin treatment of cattle can reduce tsetse survival and fecundity, but not on a cost-effective basis (Pooda et al. 2013). Fipronil has been successfully used for controlling horn flies in Latin America (Guglielmone et al. 2000); however, this active is not allowed for use in farm animals in Europe. For farm buildings, SPs (deltamethrin, cyfluthrin, and λ-cyhalothrin), organophosphates (phoxim), neonicotinoids, or similar (thiamethoxam, spinosad) are available.

The development of bacterial toxins to treat larval habitat is also an alternative: for example, the use of Spinosad® is efficient against vectors like mosquitoes that breed in water (Bond et al. 2004; Hertlein et al. 2010): Spinosad is a mixture of tetracyclic macrolide neurotoxins, spinosyn A, and D, produced during the fermentation of the soil actinomycete *Saccharopolyspora spinosa*. Its use against vectors using semi-humid breeding sites should be explored.

Use of pesticides at the necessary levels

Changes in dosages or frequency of treatment for topical insecticides currently authorized for use in cattle and sheep are off label uses and must be discouraged. Changes may lead to violative drug residues in milk or meat from treated animals. Insecticides must be applied as labeled by the manufacturer. However, long-term use of any insecticide even at appropriate levels still creates a selection pressure that will develop resistance in the target population. Thus, insecticide-based veterinary medicines must be part of the IPM strategy on livestock farms.

Availability of population dynamics models adapted to each particular situation might allow improvement in the present recommendations of the manufacturers by designing appropriate intervention thresholds and periods. Moreover, treatments can be restricted to times of the activity periods of vectors. Finally, it has been demonstrated that restricting the use of insecticides to vector biting sites using insecticide footbaths allowed a 90 % reduction of treatment time, costs, and insecticide doses in West Africa and an efficient control of tsetse flies (Bouyer et al. 2008; 2007) and trypanosomes (Bouyer et al. 2009). It was also demonstrated that this strategy has potential for limiting vector-borne zoonosis like sleeping sickness within a one health perspective (Ndeledje et al. 2013). However, its use necessitates training and guidelines (Bouyer et al. 2011a). Such strategies could be explored against European vectors since this method strongly reduces the impacts of insecticides on non-target organisms (Vale and Grant 2002; Vale et al. 2007).

Anti-resistance strategies

When animals are treated with a topical SP-based formulation, buildings must be treated with another class of pesticide. However, due to the limited number of authorized products for use as topical insecticide on animals or as residuals insecticides in farm buildings, only few combinations of drugs can be considered.

Insect growth regulators (IGRs) as veterinary medicines for farm animals have not been marketed in Europe. (S)-methoprene-based premix that has been demonstrated to be effective for control of the horn fly (*H. irritans*) (Miller et al. 1977), however, is not allowed for use in farm animals in Europe. Fluazuron (for cattle) and cyromazine (for sheep) have been included in Annex III of the MRL regulation. These IGRs would be available for pharmaceutical development. Cyromazine is marketed in Europe for building sanitization. Winter feeding sites where hay, manure, and urine are mixed together should be treated with cyromazine in May in order to inhibit larval development for the rest of the year (Taylor et al. 2012b).

Check the success of the applied measures

There are few consistent data on the assessment of control measure impact on relative abundance of nuisance fly populations in cattle operations (Vreysen et al. 2014). The interest of monitoring devices deserves to be further investigated.

Conclusions

The 2009/128/EC Directive on Sustainable Use of Pesticides provides a fruitful framework to address key elements of generic IPM strategies for cattle and sheep under European conditions. Among the eight lines of action for the implementation of IPM strategies, only two can be seriously considered, prevention, and suppression of harmful organism in the surroundings of animals (destruction of adult resting and larval development sites), and pest monitoring. Continued education of farmers and veterinarians would certainly contribute to the implementation of these basic IPM actions. Responsible use of veterinary insecticides must be encouraged. There is no room for alternate chemical compounds or significant changes in usages of veterinary medicines because of the strict-related regulations. Development of an IGR-based veterinary medicine for ruminants would be welcome. Non-chemical alternatives deserve further investigation.

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