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Review article

Helminthic control on grazing ruminants and environmental risks in South America

Victor Humberto SUAREZ*

URiSA, EEA INTA Anguil, CC 11, 6326 Anguil, La Pampa, Argentina

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Abstract – The control of ruminant gastrointestinal nematodes and ectoparasites, one of the major production health problems, are heavily reliant on the systematic and sometimes abusive use of anthelmintic drugs. Endectocides are the most frequently used drugs, having high potency against arthropods and nematodes. Their dung pat residues enhance the risk of adverse effects on non-target invertebrates and on the general grazing cattle ecosystem. In this scenario, our objective is to review current knowledge of the agro-environmental and biodiversity impact and risks of endectocides in South America. The effects of faecal drug residues of ivermectin and doramectin on dung colonising invertebrates and dung degradation have been reported in studies carried out in the temperate centre of Argentina and in the subtropical region of Brazil. The results from Argentina showed a depression in invertebrate colonisation and degradation of dung recovered from endectocide treated cattle during the autumn. Comparisons have shown that ivermectin and doramectin have similar adverse effects. A decrease of Coleoptera larvae, Diptera larvae, Staphylinidae, Collembola, Acari and dung specific nematodes was noted in pats from both endectocides. The results from Brazil showed that dipterous larvae, Polyphaga coleopteran larvae and adults and mites were significantly reduced in the ivermectin treated group. The disturbances that macrocyclic lactones can produce on non-targeted invertebrates and on their associated participation in dung degradation and soil element recycling, are unpredictable and can negatively influence biodiversity and the agricultural ecosystem sustainability.

endectocide / environmental risk / South America / cattle grazing system / dung fauna

Résumé – Contrôle des helminthes chez les ruminants à l'herbe et risques environnementaux en Amérique du Sud. Le contrôle des nématodes gastro-intestinaux et des ectoparasites, qui est l'un des problèmes de santé majeurs dans la production bovine, repose largement sur l'utilisation systématique et parfois abusive d'anthelmintiques. Les endectocides, qui ont un effet puissant contre les arthropodes et les nématodes, sont les médicaments le plus fréquemment utilisés. Leurs résidus dans les matières fécales augmentent les risques d'effets nocifs sur des invertébrés qui ne sont pas la cible

*Correspondence and reprints
Tel./fax: (54) 2954 495057; e-mail: vsuarez@anguil.inta.gov.ar

des traitements, et sur l’écosystème général des bovins en pâture. Dans ce scénario, notre but est de faire une synthèse des connaissances actuelles concernant l’impact et les risques liés à l’utilisation des endectocides sur l’environnement agricole et sur la biodiversité en Amérique du Sud. Les effets des résidus fécaux d’ivermectine et de doramectine sur les invertébrés colonisant les matières fécales et sur la dégradation de celles-ci ont été reportés dans des études menées dans la région centrale tempérée d’Argentine et dans la région subtropicale du Brésil. En Argentine, les résultats ont montré une diminution de la colonisation par les invertébrés et de la dégradation des matières fécales provenant des bovins ayant reçu des endectocides durant l’automne. Des comparaisons ont montré que l’ivermectine et la doramectine avaient des effets nocifs similaires. Une diminution de larves de coléoptères et de diptères, de Staphylinidae, de Collemboles, d’acariens et de nématodes spécifiques des matières fécales a été notée dans les crottes contenant les deux endectocides. Les résultats de l’étude menée au Brésil ont montré que les larves de diptères, les larves et les adultes de coléoptères Polyphaga, ainsi que les acariens, étaient significativement moins nombreux dans le groupe traité par l’ivermectine. Ces perturbations, pouvant être produites par les lactones macrocycliques sur des invertébrés non-cibles, et sur leur participation à la dégradation des matières fécales et au recyclage des éléments du sol, sont imprévisibles et peuvent influencer de manière négative la biodiversité et la durabilité de l’écosystème agricole.

endectocide / risque environnemental / Amérique du Sud / élevage bovin à l’herbe / faune des matières fécales

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1. INTRODUCTION

South American agriculture has fallen into a complicated economic situation. Net returns from its traditional exportable animal products, such as meat, milk and wool, have decreased significantly. This situation of productive constraints is related to the structural economic transformations produced on the continent, added to the decrease of international commodity prices and the recent South American outbreaks of cattle foot-and-mouth disease. In this scenario, animal production strives for increased economic efficiency at the risk of greater biological or environmental costs. Extensive grazing in subtropical deforested areas or intensive grazing in agricultural-cattle systems are alternatives to compensate for depressed meat prices or high imputed costs. In tropical and subtropical areas of South America large marginal forested areas have been transformed into arable crops and animal production areas. Likewise, production systems of the rich temperate plains of the southern cone of the continent have been intensified, increasing the fossil energy status. These short-term high yield processes expose the environment to rapid degradation with devastating effects on regional economics. Productivity, stability and sustainability are qualities that characterise livestock and agricultural ecosystems, which are generally in permanent conflict [21].

In this context, intensive livestock systems have based their productivity on nutrition, genetics and health management that contrast with the stability of the ecosystem, limiting the pastureland system sustainability. Within grazing animal health integrity, parasite infections are one of the major causes of disease and economic loss and their control is a necessity. Productive assessments have demonstrated that parasitic losses in intensive systems can be enormous [3, 28, 29].

2. CHARACTERISTICS OF ANTHELMINTIC CONTROL STRATEGIES

During the last 15 years in South America, technologies for gastrointestinal nematode control in livestock have been sustained by the use of broad-spectrum anti-parasitic drugs. Lately, in this region negative economic pressures have decreased net return margins and forced the intensification of livestock production. In parallel, anthelmintic costs have decreased and induced livestock managers to over-use these drugs. During the last decade, benzimidazoles and endectocides were the most frequent anti-parasitic drugs used.

In sheep production, benzimidazoles, mainly with an oral formulation, were the most used anthelmintics. However, lately benzimidazoles have been replaced by endectocides, closantel and organophosphate drugs, because of the apparition of anthelmintic resistance to benzimidazoles [8].

In South America, with the exception of Uruguay, the cattle industry is the most important animal production. Benzimidazoles, mainly with intra-ruminal or injectable (ricobendazole) formulations are still being frequently used, because of their good efficacy. However, in recent years endectocide use has become more and more important on the anti-parasitic market. Currently, the injectable formulation of these drugs is the most used. These preferences and their massive use, is mainly a consequence of their persistent effect, their activity against ectoparasites [5], easy administration and lately, the high depression of their prices, mainly of the generic products. The pour-on formulation and sustained-release boluses have been little diffused because of their high prices.

The control strategies and the use of endectocides change according to the region. In marginal semiarid regions with extensive cattle systems, farmers only treat calves once or twice a year. Along the subtropical deforested area or plains, the treatments are more frequent (3 to 5 times per year) and with the aim to control both internal and external parasites with persistent drugs over long periods. But in the temperate plains of the southern cone, where mixed grain crop-cattle production systems predominate, management is very intensive and drugs are being used more and more frequently (4 to 9 times per year) and with an increased anthelmintic persistence. Current parasite control programs integrate both endectocides and benzimidazoles, although they are more and more based on endectocides due to the long-acting control of a broad range of parasites. In addition, new products with high drug concentrations have become more frequent, such as long-acting injectable formulations or eprinomectin for dairy cattle.

Currently, reports of the advent of genetically modified food products, of animal disease outbreaks, and drug residues have heightened consumer preoccupations about food quality. In this scenario, programs heavily reliant on the systematic and sometimes abusive use of chemicals are being drawn to the attention of consumers. Increasingly, citizens are more and more concerned about the detrimental consequences of drug residues on biodiversity, environmental sustainability and food safety [19]. In addition, another unwanted result of chemical over-use is the appearance of anthelmintic resistance in cattle [1, 4, 30].

3. ENDECTOCIDES AND ENVIRONMENTAL RISKS

Endectocides are macrocyclic lactones including some avermectins registered for use in this region such as ivermectin, abamectin, doramectin and eprinomectin and one milbemycin, moxidectin. These macrocyclic lactones are very safe and effective and very powerful broad-spectrum parasiticides against a wide range of nematodes and arthropods. Avermectins cause paralysis by ingestion or contact and eventually death of invertebrates and several sublethal metabolic disorders [5]. There is substantial evidence that their effects result from an increased release of the neurotransmitter γ-aminobutyric-acid (GABA) and enhanced binding of GABA to its postsynaptic receptors, which leads to the consequent opening of chloride ion channels and decreased cell function. Also, there is evidence that avermectins also target chloride channels independently of GABA [5].

The type of the endectocide drug, the dosage, solvent and route of application affect their persistence and efficacy [11]. These drugs have a prolonged efficacy, depending on the formulation or the type of the drug, from 8 to more than 30 days. Injectable drugs in non-aqueous formulation are a key factor for the persistence of the drug half-life. Topical pour-on dosages increase the initial drug concentration [20], while oral formulations are water-based and have less persistence. Drug delivery systems have become important for persistence, such as sustained-releasing boluses that release therapeutic amounts of drugs for periods of more than 3 or 4 months. However, endectocides are partially metabolised during their passage through the host and are eliminated in great concentration in the faeces, showing a prolonged persistence and toxic side effects on dung-living invertebrates.

Researchers initially reported the high drug effect on target-pest insects, such as *Haematobia irritans* that develops a life cycle stage in the dung pat [17]. These findings later induced investigations that drew attention to the adverse effects of avermectins on non-target insects of the dung [31]. Actually, there is some information from other parts of the world on the potential ecological risks of these drugs. Results from North America, Europe and Australia [11, 16, 31, 32] have shown that avermectins exert non-specific effects, having the toxicity to kill or disrupt the development of a wide variety of insects of the dung pats. The faeces from cattle treated with ivermectin or abamectin were toxic for dung beetles during 2–4 weeks. The effects of these drugs on the invertebrate dung community and their observed consequences on the rate of dung breakdown, make it necessary to consider other related consequences such as soil fertility, pasture productivity and wider pastureland ecological disturbances [22].

4. IMPACT OF ENDECTOCIDES ON COPROPHILOUS FAUNA IN SOUTH AMERICA

Current knowledge on the agro-environmental impact of endectocide control strategies in South America is scarce, in spite of their intensive use. Only a little recent information from Argentina and Brazil, which estimates the avermectin effect by means of the level of cattle dung pat invertebrate colonisation and faecal dispersal, is available. These studies were situated in the tropical highland region of Minas Gerais (Brazil) with dairy cattle and in the temperate western Pampeana Region (Argentina) with meat cattle.

In Brazil [15], the trials were carried out during the drought season in July and the design compared faeces from bovines treated with ivermectin (0.2 mg/kg of live weight) and untreated bovines. On 0, 3, 7, 14, and 28 post-treatment days, the faeces were recovered and deposited in the field. An Argentinean study [27] had a similar design, but was realised during the autumn and spring and comprised faeces recovered from 3 cattle groups. One group was injected with ivermectin (0.2 mg/kg live weight), another group with doramectin (0.2 mg/kg live weight) and there was an untreated control group. Fifty 550 g dung pats per group were prepared and deposited on the field, on 3, 7, 16 and 29 post-treatment days. Dung pats were recovered for wet weight, dry-matter and fauna estimations, after 10, 30, 60 and 7, 14, 21, 42, 100, and 180 days in the field respectively in Brazil and Argentina.

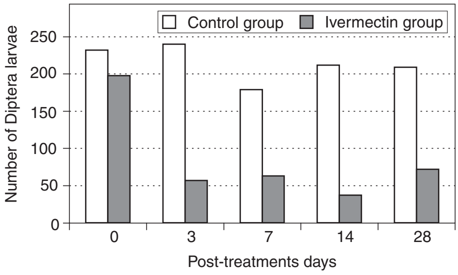

Figure 1. Added total number of Diptera larvae found in 14 cattle pat samples of 100 g recovered from the field after 10 and 30 days. Fresh dung pats were from the ivermectin-injected group and the untreated control group and were deposited on 0, 3, 7, 14 and 28 days after treatment (Iglesias unpublished data).

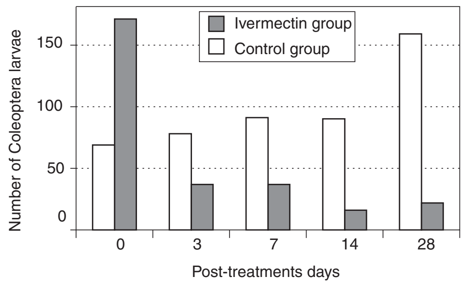

Figure 2. Added total number of Coleoptera larvae found in 14 cattle pat samples of 100 g recovered from the field after 30 and 60 days. Dung pats were from the ivermectin-injected group and the untreated control group and were deposited on 0, 3, 7, 14 and 28 days after treatment (Iglesias unpublished data).

4.1. Effects on dung arthropods

Similar results were obtained for arthropods in both regions, with significant reductions of their numbers in the faeces from endectocide treated cattle.

In Brazil, Iglesias et al. [15] showed a reduced number of Diptera larvae in the treated group from 3 to 28 post-treatment days after 10, 30 and 60 days in the field (Fig. 1). Thirty days after faeces deposition in the ivermectin group a significantly small number of Coleoptera larvae were recovered from 3 to 28 post-treatment days (Fig. 2). Similarly, in Argentina [27] after 21 days in the field, the total number of arthropods of the control group were higher than those of the ivermectin and doramectin group from the 3rd to 28th post-treatment days. Figure 3 shows total arthropod counts recovered from pats exposed after 7, 14, 21, 42, 100, 180 days on the field. A decrease of Coleoptera larvae and Diptera larvae was noted in pats from ivermectin and doramectin groups in all depositions exposed since the 21st day. Figure 4 shows the

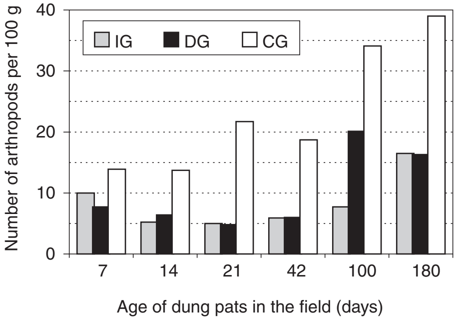

Figure 3. Mean total arthropod number recovered in 100 g of fresh pats exposed after 7, 14, 21, 42, 100, 180 days on the field. Dung pats were from cattle groups injected with ivermectin (IG), doramectin (DG) and untreated controls (CG). Data are from Suarez [27].

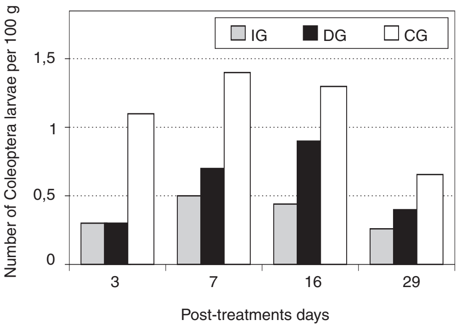

Figure 4. Mean number of Coleoptera larvae recovered in 100 g of fresh pats deposited 3, 7, 16 and 29 days after treatment. Dung pats were from cattle groups injected with ivermectin (IG), doramectin (DG) and untreated controls (CG). Data are from Suarez [27].

decrease of Coleoptera larvae of treated groups in all depositions. These South American results give evidence of a toxic effect of avermectin for larval stages of Coleoptera and Diptera 28 days after treatment. Several overseas studies on dung beetles have reported similar results [11, 25, 32], finding that faeces dropped during the 2nd and 4th week after injection with ivermectin and abamectin cause mortality and nutritional, developmental, fertility and sexual sublethal problems on larval stages.

Adverse effect differences of endectocides on dung invertebrates are related to differences in life cycles, feeding or reproductive habits and stages; larvae and young adults are more susceptible [22]. Non-target and target Diptera larvae, which in some seasons are very important to dung aeration, react negatively but not in the same way to endectocides. Nematocerous Diptera are able to tolerate dung, 10 days after treatment, while Cyclorrapha [16] or *Musca vetustissima*, *Musca domestica,* and *Haematobia irritans* [33], remain at risk for a period of 30–35 days. These avermectin effects range from acute or chronic mortality by paralysis and feeding or growth and moulting interference [23], or sublethal and long-term consequences like reproductive deficiencies [14] or external structural abnormalities [6].

There are few reports on other arthropods with the exception of South American works. These studies showed that ivermectin and doramectin bovine treated faeces interfere with a number of minor arthropods like Staphylinidae, Collembola and mites. Staphylinidae [26] were found in an inferior number until 3 weeks post-treatment and 42 days post-deposition.

Micro arthropods are negatively affected by avermectins. In Argentina [27], in faeces from both ivermectin and doramectin injected cattle, the number of Collembola and mites was respectively reduced until the 16th and 28th post-treatment days at 2 and 3 weeks in the field. Iglesias et al. [15] in Brazil, reported that mites of several sub-orders (Gamasida, Oribatida and Acaridida) are reduced in ivermectin cattle treated dung. The food source of these micro arthropods and also nematodes are based on bacteria and saprophytic fungi [18]. The consequences of the endectocide residues on these invertebrates and on the high degree of interactions among these species and the whole dung food web need to be elucidated.

4.2. Effects on the attractiveness to dung beetles

Holter et al. [13], and Wardhaugh and Mahon [32], found under field observation in Europe, Africa and Australia, that dung pats from cattle treated with avermectins are in some cases more attractive to dung burying beetles than control pats. It appears that avermectins per se are not the cause, but some unknown side effects stimulate changes in the intestinal flora that make dung more attractive. Conversely, studies from the Pampeana region [27] did not find any differences in dung beetle attractiveness between ivermectin or doramectin treatments and control pats. In the same way, studies of Strong and Wall [24] and Strong et al. [25] in Europe did not observe any repellent effect from the faeces of ivermectin treated cattle and controls.

4.3. Effects on nematodes and annelids

Little information is available about the endectocide effects on dung free-living nematodes, many of which are fungivorous and help to reduce fungal populations. Suarez [26] reported that the number of free-living nematodes recovered from control dung pats was three times that of treated dung pats. This adverse difference was noted in dung collected up to two weeks after injection and after three weeks in the field. Figure 5 summarises the mean drug adverse effects on dung nematodes during the study [27]. The observations of Barth et al. [2] pointed out that only some of the species of dung specific nematodes occur in reduced numbers in pats from the ivermectin bolus treated cattle.

Little attention has been paid to the adverse effects of endectocides on annelids. The presence and number of earthworms are not affected by avermectins [16, 23]. Conversely, in vitro experiments [10] showed impaired growth and poor reproduction performance and increased mortal-

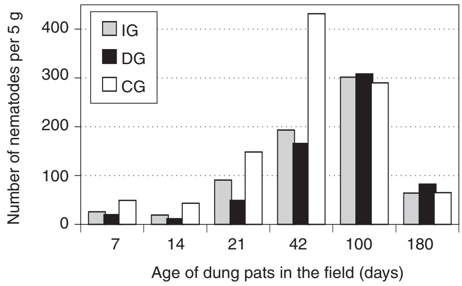

Figure 5. Mean number of free-living nematodes recovered in 5 g of fresh pats exposed after 7, 14, 21, 42, 100, 180 days on the field. Dung pats were from cattle injected with ivermectin (IG), with doramectin (DG) and untreated controls (CG). Data are from Suarez [27].

ity on the earthworm *Eisenia fetida* in soil with ivermectin. These contradictory results underline the importance of additional investigation on endectocide effect on earthworms.

5. BIODIVERSITY AND ENVIRONMENTAL EFFECTS

Livestock and agricultural activities have caused a detrimental impact on the environment and the subsequent alteration of the original fauna, flora and soil composition. It is known that in cattle grazing systems, decomposing cattle dung pats help to maintain pastureland natural resources and productivity by recycling nutrients to the soil. A diverse community of organisms, such as arthropods, nematodes, fungi, bacteria and annelids live in close association with dung pats, playing an important and varied role in the dispersion of the dung into the soil. The value of dung fauna is well recognised, but the significance of the future global effects of endectocides on the biodiversity and structure of this dung community and future nutrient recycling is unknown [23]. In addition, the environmental consequences of endectocide utilisation may be the effects on vertebrate predators of dung fauna, pollinators and subsequent habitat fragmentation or disruptions in the food web. Furthermore, we have insufficient knowledge on the global consequences of drug disturbances on the biodiversity and the ecological functions of target and non-target organisms [19].

6. EFFECTS ON DUNG DEGRADATION AND PERSISTENCE

Some investigations from Europe, which used pat mass as an indicator, showed that avermectin treatments reduce the rate of breakdown of pats [2, 16, 23], while some other controversial works have communicated no adverse effects on dung dispersal following avermectin treatments [25, 35]. In a study during the autumn in Argentina [26], significant delays in the rate of degradation of those pats from cattle injected with ivermectin and doramectin, using reduced pat weight as an indicator, were reported (Fig. 6). However, observations from Brazil did not report differences in the rate of pat breakdown of faeces from treated and untreated cattle groups [15].

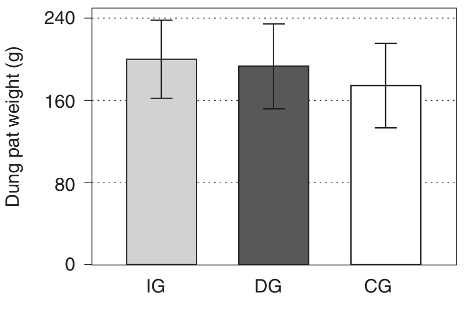

Figure 6. Total mean wet weight (g) and standard error of artificial dung pats (200 replicates per group) collected after 7, 14, 21, 42, 100, 180 days on the field. Dung pats (initial weight: 550 g) were from cattle injected with ivermectin (IG), doramectin (DG) and untreated controls (CG). Data are from Suarez [27].

Despite the active effect of dung fauna on the dispersal of the dung [12], these controversial results may have been influenced by several factors. Some of them may be the different type of experimental designs, methods to evaluate pat degradation or different drug formulation or administration. Likewise, other factors considered were the level of intensity of the rainfall or the different composition of dung fauna and their seasonal variation. Different regional dung fauna communities and different avermectin susceptibilities between the principal species that destroyed the pats are expected. For example, in those regions where scarabaeine dung beetles are often the first to colonise and are the most important dispersers of dung, such as in South American, Australian or African subtropical regions, ivermectin residues may not exert a negative direct effect on the adult beetle stages and on the subsequent dung degradation. However, residues may exert an indirect and long-term effect on larval stages and on adult reproductive performance. In other temperate regions such as in northern Europe where little coleopteran or fly larvae are the most important for dung dispersal, their mortality caused by avermectins directly affects the degradation and dung dispersal [23].

Several studies have shown the remarkable stability and persistence of ivermectin in intact dung pats left on the pastureland and the biological activity of residues against dung fauna [16, 20]. Our unpublished results from temperate areas of Argentina reported concentration percentages of 21% and 42% respectively of the initial ivermectin and doramectin concentrations excreted in the faeces for approximately six months in the field. These drugs showed high stability with no apparent degradation over that period. These high levels of residues explain the reduced number of arthropods obtained from dung from treated cattle after 100 days in the field [27].

7. DIFFERENCES BETWEEN ENDECTOCIDES FOR RESIDUE TOXICITY

The results in Argentina [26] showed a similar depression in invertebrate colonisation and degradation of dung recovered from ivermectin and doramectin injected cattle during the autumn. Wardhaugh and Mahon [33] in Australia observed that injectable formulation of abamectin and ivermectin appear to be equally toxic for larvae of *Musca vetustissima*, while the oral formulation of ivermectin seems to be less harmful. Strong et al. [25], working with cattle dung following the administration of ivermectin sustained–release boluses, conclude that residues prevent fauna colonisation 3-weeks after administration. Errouissi et al. [9] reported that the administration of ivermectin sustained-release bolus to cattle is highly effective in killing dung beetle larvae of *Aphodius constans* for approximately 143 days after treatment. However, macrocyclic lactones including moxidectin, a milbemycin, seem to be less harmful to arthropods than ivermectin [11]. Moxidectin is less toxic to *Onthophagus gazella* and *Haematobia irritans exigua* than abamectin and a 64-fold higher concentration of moxidectin than abamectin is required to produce similar toxicity [7]. Strong and Wall [24] did not find differences between dung fauna colonisation from moxidectin-injected cattle and controls. Wardhaugh et al. [34] compared the biology of the dung beetle *Onthophagus taurus* in faeces of cattle treated with pour-on formulations of eprinomectin and moxidectin. Eprinomectin faeces are associated with high juvenile mortality during the first 1–2 post-treatment weeks. In contrast, faeces from moxidectin have no detectable effects on the development and survival of dung beetles.

8. CONCLUSION

Several nutritional, genetic or health practices for ruminant productivity are opposed to stability and a sustainable production, and this concept and others like the quality and origin of animal products have become more widespread as public consciousness has grown. A number of current agricultural intensive practices are degrading the environment. These problems in South America are critical due to the fragility in most of the livestock lands, the future demand for zero residue limits in animal products and the increasing dependence of exports of "green" commodities. The intensive grazing systems for cattle production should be sustainable if soil fertility reduction, as a consequence of the extraction in animal products, is mainly compensated by the excrement nutrient return. In this context, endectocides are of considerable value in animal production, but at an unevaluated environmental cost. Investigations have shown the adverse lethal and sublethal effects of broad-spectrum endectocides on non-target dung fauna, although current knowledge is limited. In addition, the long-term adverse effects of the endectocide used on cattle grazing systems are largely unknown. Long-term integrated studies with different types of designs are needed to be able to formulate conclusions about the wider pastureland implications of parasite control strategies. We also need more knowledge on the ecological limits of endectocide impact and on what levels of biodiversity are necessary to maintain the nutrient cycling, soil fertility, pasture production and sustainable livestock activity.

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