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Control of western corn rootworm damage by application of soil insecticides at different maize planting times

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ABSTRACT

The western corn rootworm, *Diabrotica virgifera virgifera* LeConte (Coleoptera: Chrysomelidae) (WCR), is one of the most damaging maize crop pests. Damage to maize is primarily caused by the larvae feeding on roots, which results in a reduction of water and nutrient uptake and may cause lodging as well as a substantial reduction in grain yield.

The effects of soil insecticides, applied at different planting times, on controlling WCR damage were investigated in 76 naturally infested fields in Northern Italy over a 4-year period. Without furrow insecticides, plant density was reduced at all of the considered planting times (−5%). Insecticide application led to a significant reduction in the WCR larval density (−43%). As a consequence, the root injury measured by node injury scale, was reduced (−65%) as was the incidence of plants with "gooseneck" symptoms (−76%). Furthermore, the soil-applied insecticide plots showed a significant increase in plant biomass yield at the dough stage (+6%) and in grain yield at physiological maturity (+8%). The application of soil insecticides showed a positive yield increase in 95% of the compared production situations. The yield increase was higher than 5% in 70% of considered cases. The effect of the soil-applied insecticides on root and plant damage symptoms, and the consequent biomass and grain advantage were steady over the different intervals between planting time and WCR egg hatching.

The results of this study have underlined that the application of a soil insecticide to the furrows at planting leads to a clear control of injuries from insects and a consequent maize yield advantage.

1. Introduction

The Western Corn Rootworm (WCR), *Diabrotica virgifera virgifera* LeConte (*Coleoptera: Chrysomelidae*) is a dangerous maize (*Zea mays* L.) pest in several countries. It is native to Central America, and it has been recognized as one of the most destructive pests in the Midwestern United States since the middle of the last century (Park and Tollefson, 2006). In Europe, WCR is considered an invasive species, which was accidentally introduced through multiple events from the early 1980s till the 2000s (Lemic et al., 2015). WCR was reported for the first time in 1992 in Serbia. After introduction and establishment, WCR spread rapidly to other European maize growing areas and it has currently reached high population levels in central - southern Europe, including Northern Italy (Kiss et al., 2005). Economic damage is more common in areas in which maize is grown as a continuous crop and where the environmental conditions are favourable to the building of high WCR populations.

According to Boriani et al. (2006) an action threshold of about 5 adults/trap/day is used to evaluate captures with 6–8 Pherocon® AM yellow sticky traps/field (depending on field size), over a six/eight-week period. Economic damage has been reported in several growing seasons and areas of Northern Italy, when the adult captures exceed this threshold, without insecticide application (Blandino et al., 2014).

Since WCR larvae only feed on maize roots and can only survive in small numbers on a limited number of non-maize grasses (Oyediran et al., 2004), crop rotation has proved to be an effective

Abbreviations: DM, dry matter; GDD, growing degree days; GS, growth stage; IPM, Integrated Pest Management; NIS, node injury scale; PS, production situation; RR, relative ratio; WCR, Western Corn Rootworm.

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pest management strategy when the action threshold is exceeded. However, the intense use of a simple crop rotation, such as the maize-soybean rotation adopted in the Midwest in the USA, has selected for an insect strain that can lay eggs in soybean fields. The larvae hatching from these eggs emerge into maize fields the following spring (Gray et al., 2009).

Crop rotation is also the main effective integrated pest management (IPM) control option adopted in Europe. However, in the more profitable maize growing areas where continuous maize is preferred, if the pest is widespread and reaches high population levels, soil and/or foliar insecticides are applied frequently. Insecticide sprays used to control the adults can be applied at the beginning of female egg laying to reduce oviposition or, in case of extremely high infestation, before silking to reduce silk feeding by WCR adults. In this case, the timing of the insecticide application is critical, and needs precise knowledge on the phenology of the WCR population in the field.

The most common strategies used to protect maize roots from WCR are the application of a soil insecticide at planting, and the use of an insecticide seed dressing (Sutter et al., 1990; van Rozen and Ester, 2010) when available. Numerous conventional insecticides, in granular and liquid formulations (pyrethroid, organophosphate, neonicotinoid, and phenyl pyrazole classes), are registered for WCR larval control in Europe. These active ingredients have also been proven to control other soil insects that could attack maize seedlings, and thus reduce plant density, such as *Agriotes* spp. wireworms (Ritter and Richter, 2013).

In recent years, the use of maize seeds treated with insecticides belonging to the neonicotinoid class has been restricted in several European countries because of their adverse effects on honeybees (Girolami et al., 2012). This restriction has led to a notable increase in soil insecticide applications for maize crops, thus raising concerns about their undesired side effects on the agroecosystem and non-target organisms, and about their effective benefit to the crop (Furlan and Kreutzweiser, 2015).

The effectiveness of soil-applied insecticides and seed dressings is variable and still debated (Cox et al., 2007), and there are different opinions concerning the effect of planting time applications. Some authors claim that they are ineffective in WCR control and eradication programs (Furlan et al., 2006), but their efficacy in containing root damage has been confirmed. The effects on yield of soil insecticides, such as tefluthrin, thiamethoxam, tebupirimphos and cyfluthrin, are reported to be quite inconstant, varying from no effect to an increase of more than 60% (Cox et al., 2007, 2008; Ma et al., 2009; Dun et al., 2009; Petzold-Maxwell et al., 2013). Many factors can affect the efficacy of soil treatments: the interactions between planting time and soil texture, application depth, organic matter, pH and weather conditions (rainfall), with consequent variable effects on its persistence. In addition to leaching, insecticide persistence could be affected by volatilization and chemical degradation with higher temperatures and lower soil moisture levels (van Rozen and Ester, 2010; Furlan and Kreutzweiser, 2015).

In order to address the control strategies for this pest in Europe correctly, there is an urgent need to assess the impact of soil-applied insecticides to control WCR and develop integrated strategies to minimize yield loss in different environments. While the effect of selected insecticides on the control of WCR has often been mentioned under experimental conditions at a single field scale, or in semi-field conditions with artificial rootworm infestations or in small-plot studies (Sutter et al., 1990; Magalhaes et al., 2007), its evaluation under natural infestation conditions at a regional scale has been investigated less (Kuhar et al., 1997; Fuller et al., 1997), especially in Europe where this invasive species is still spreading.

The aim of this study was to verify the effect of soil insecticides on the control of WCR damage and quantify the related yield advantage in naturally infested fields. The effect of the insecticides applied at planting has been investigated in different production situations for full-season maize hybrids in Northern Italy, but considering different intervals between the application times (planting) and the occurrence of the WCR larvae in the field, or different agronomic conditions for soil tillage and irrigation.

2. Materials and methods

2.1. Experimental set up

The effect of soil insecticide application in seed furrows at planting on the control of WCR larval damage and the consequent maize yield was investigated in 76 production situations (PS) over a 4-year period (2010–2013) in Northern Italy. In each location the soil insecticide application at planting time was compared to an untreated control using a completely randomized block design with 3 replicates per treatment. The plots were all 20 m long and 8 rows wide and they were staked out side by side in a fully planted field. Row distance was 0.75 m, while plant distance per row was 0.17–0.20 m according to maize hybrid maturity group. All the measurements were conducted in the two middle rows.

A list of the compared PS and their main geographic and agronomic information is reported in Table 1.

The choice of the experimental sites was made considering fields with a high WCR infestation recorded in the previous year (above the threshold of 5 adults/trap/day with Pherocon® AM traps), according to the information obtained from the adults territorial monitoring and for which a high presence of the pest might be expected during the survey. Moreover, the previous crop was always continuous maize cultivated without any former foliar insecticide application to control WCR or other maize pests.

The effect of soil insecticide application was evaluated considering different intervals between planting time and expected egg hatching. The compared PS were subdivided into 3 groups on the basis of the interval of cumulated growing degree days (GDD) from the maize planting date to the end of egg hatching, expressed as the 90% of 1st instar WCR larvae cumulative occurrence (WCR90%). The logistic equation developed by Davis et al. (1996) with a minimum and maximum developmental threshold for the WCR larvae of respectively 11 °C and 18 °C was used to calculate the cumulated GDD from January 1st to WCR90% and to the maize planting date of each PS. The quantification of the cumulated GDD interval between maize planting date and the end of egg hatching (MP-WCR90%) was performed using the maximum and minimum air temperatures recorded by weather stations located next to each experimental site.

In order to obtain an equal distribution of recorded cases, the considered PS were subdivided into the following MP-WCR90% classes: GDD <150 °C d^{-1} (21 cases), 150–230 °C d^{-1} (28 cases), and >230 °C d^{-1} (27 cases).

The soil insecticide was distributed using a calibrated granular dispenser or sprayer applied to the planter. The insecticide was distributed in seed furrows at a depth of 5–10 cm from the soil surface at the recommended rate for each product according to the equipment setting and the desired seeding depth. No insecticide was applied as a seed dressing in any of the tested PS. The applied soil insecticides belong to the pyrethroid, neonicotinoid or organophosphate classes, and they are listed in Table 1. The formulation and the application rate are reported in the table footnotes.

The considered PS included the use of full season maize for both grain and whole plants as silage. The maturity class (FAO 500–700) of the tested hybrids was selected according to the characteristics of the growing area and the adopted planting time. Different irrigation systems were adopted, according to the typical farm