Economic Injury Level of *Armadillidium vulgare* (Crustacea: Isopoda) on Sunflower

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ABSTRACT

- Under no-tillage systems *Armadillidium vulgare* has found an adequate environment for its development and reproduction and it has become one of the most important pests in sunflower crops in Buenos Aires, Cordoba and Entre Ríos provinces, Argentina. This specie cause damages to plants at sowing and immediately after germination. Integrated Pest Management (IPM) is a basic tenet of the sustainable agriculture. The Economic Injury Level (EIL) is an important component of cost-benefit in IPM program and is a useful tool for decision-making in application of pesticides. The EIL represents the lowest pest density that can be tolerated and this concept represents a theoretical foundation for IPM. Development and use of EIL is a priority in any agenda of MIP for sustainable agriculture. The aims of the present work were: i) evaluate damages of *A. vulgare* on sunflower crops and ii) determine the damage function which allows estimates EIL of *A. vulgare* on sunflower.
- Two field studies were conducted in 2009/10 and 2010/11 cropping seasons in the Balcarce Agricultural
- Experimental Station of NIAT (37º45' S; 58º18') to estimate EIL based on the relationship between densities of *A. vulgare* adults and yield losses. Treatments were arranged in a randomized complete block with 5 replicates. Experimental units (EU) were 1m^2 of soil surrounded by metal frame. In each EU 8 sunflower seeds (cv. Aconcagua) were sown. Treatments were artificial controlled *A. vulgare* infestation: 0, 20, 40, 60, 80 and 120 individuals m^{-2}. The selected individuals had 26 to 80 mg of body weight. Plant damage was recorded after sowing and crop yield were recorded at maturity. To test for differences in the plant damages between *A. vulgare* densities we performed one-way ANOVA. Damage function was estimated from the regression of *A. vulgare* adult density and percentage yield loss. The EILs was estimated by using Pedigo et al. (1986) model as follows: $EIL=C/(V\times D\times K)$, where C is the control costs per production unit, V is the market value per production unit, D is the slope of the regression of *A. vulgare* density on percentage yield loss, and K is the reduction of injury due to treatment.
- *Armadillidium vulgare* injury on sunflower plants was done on cotyledons and hypocotyls, principally. The proportion of damages plants progress until 15-17 days after sowing. In 2009, a higher proportion of severe damages (more than 50% of damage in hypocotyl) were observed with 60 and 120 individuals m^{-2} respect to control without any individuals ($p< 0.05$). While in 2010, this was observed only with 120 individuals m^{-2}. In both years, total damages were similar between all treatments ($p> 0.05$) and these differs respect to control ($p< 0.05$). The relationship between *A. vulgare* densities and sunflower yields lost was used to develop damage function and to generate EILs in relation to dynamic changes in sunflower prices, control costs, and pest control efficacy. Using Pedigo´s et al. (1986) model EILs were calculated for a wide range of reasonable scenarios. Only 2009/10 infestation data provided significant regression between density of *A. vulgare* and sunflower yield-loss (damage function). The percentage yield loss–*A. vulgare* density relationship gave a positive linear yield function ($\hat{y} = 0.351x - 1.774$, $p< 0.05$). With this equation, an average of 1 individual of *A. vulgare* m^{-2} reduced the sunflower yield by 0.351%. Estimated EIL ranged from 35 to 95 individuals m^{-2} considering mean sunflower prices and yields, mean control costs and different pest control efficacy.
- We concluded that sunflower damages and yield losses depend of *A. vulgare* density. It was determined the fundamental concepts of EIL, relationship between *A. vulgare* density and sunflower yield losses or damage curve. It allows estimate EIL, it is an important conceptual and practical tool for decision making in IPM programs. This information may be considered by plantation managers as a first order guideline for pest management decision-making to use pesticides correctly and conserve environmental quality.
- Studies of *A. vulgare* as sunflower pest are virtually null worldwide. In this sense, the present study represents the first source of information on the *A. vulgare* management. Based on damage curve, EIL must be recalculated when market value, management cost and pesticides efficiency change. Further research needs to be done to achieve more accuracy on the damage curve parameters estimation.

Key words: Damage function, No tillage, Integrated Pest Management, Pill bugs.

INTRODUCTION

In Argentina, as well as in other parts of the world, during the 1970s, an "agriculturization" process has occurred, producing severe soil erosion (Manuel-Navarrete et al., 2005). In response to this problem, farmers have adopted a conservation tillage system such as no-tillage as a soil-protecting measure (Studdert and Echeverría 2000; García-Préchac et al., 2004). In conservation-tillage systems, litter and soil organic matter tend to concentrate in the upper 5 cm layer of soil (Dominguez et al., 2005). The litter layer is a very important factor in ameliorating soil temperature and moisture extremes (Cox et al., 1990; Dominguez et al., 2005; Triplett and Dick, 2008), which provides a more stable environment for soil- and litterdwelling invertebrates (Stinner and House, 1990). Thus, under no-tillage systems *Armadillidium vulgare* (Latreille, 1884) (Crustacea: Isopoda) has found an adequate environment for its development and reproduction and it has become one of the most important pests in sunflower crops under that tillage system in Buenos Aires, Cordoba and Entre Rios provinces (Trumper and Linares, 1999; Saluso, 2004; Mastronardi, 2006; Faberi et al., 2010). Damage to plants is caused at sowing and immediately after germination, *A. vulgare* feeds on seeds and seedlings, causing a reduction in plant density.

No concept has influenced the direction of pest technology in the last decades more than Integrated Pest Management (IPM) (Bird and Bremer, 2006). The major goals of IPM include reducing pest status, accepting the presence of a tolerable pest density, conserving environmental quality and improving the sustainability of the system. Pest management rests on the premise that not all pests required management; some levels of pests are tolerable. According to that premise Stern et al., in 1959 (in Pedigo and Higley, 1996) proposes the Economic Injury Level (EIL) concept to assess pest status. EIL represent the lowest population density that will cause economic damage or the amount of pest injury which will justify the control costs (Pedigo and Higley, 1996). The primary purpose of EIL development was to apply pesticides in a rational and judicious manner, thus helping to alleviate ecological problems within agroecosystems. Considering this, further development and use of standard EILs should be a priority in any serious agenda for environmental conservation and sustainable agriculture. In this context, the aims of the present work were: i) evaluate damages of *A. vulgare* on sunflower crops and ii) determine the damage function which allows estimates EIL of *A. vulgare* on sunflower.

MATERIALS AND METHODS

Individuals of *A. vulgare* were obtained from a wild population in a natural field of the Balcarce Agricultural Experimental Station (AES) of National Institute of Agricultural Technology (NIAT) (37º45' S; 58º18' O, 120m asl), Argentina. Individuals were collected by hand from leaf litter and they were placed in plastic containers to carry them to the laboratory where they were weighed in an electronic analytical balance (precision ± 0.001 g). Individuals were kept in translucent plastic containers (20 cm long, 15 cm wide, and 10 cm deep, base layer of plaster of Paris) to ensure that we had individuals to select at the beginning of the assays.

Two field studies were conducted in 2009/10 and 2010/11 cropping seasons in the Balcarce AES of NIAT to estimate EIL based on the relationship between densities of *A. vulgare* adults and yield losses. Treatments were arranged in a randomized complete block with 5 replicates. Experimental units (EU) were $1 m^2$ of soil (2 m long x 0.5 m wide) surrounded by metal frame of 30 cm high of which 10 cm were buried in the soil. In each EU 8 sunflower seeds (cv. Aconcagua) were sown and different density levels of *A. vulgare* were maintained. Treatments were artificial controlled *A. vulgare* infestation: 0 (control), 20, 40, 60, 80 and 120 individuals m^{-2}. The selected individuals had 26 to 80 mg of body weight. Plant damages were recorded after sowing and crop yield were recorded at maturity according to Pereyra and Farizo (1979). Damages were categorized as: slight damages (superficial damages), moderate damages (less than 50% of hypocotyl and cotyledons damage) and severe damages (more than 50% of hypocotyl and cotyledons damage).

To test for differences in the plant damages between *A. vulgare* densities we performed one-way ANOVA, and treatment means were separated using LSD tests. Damage function was estimated from the regression of *A. vulgare* adult density and percentage yield loss. The EILs was estimated by using Pedigo et al. (1986) model as follows:

$$EIL=C/(V\times D\times K)$$

Where: *C* is the control costs per production unit (pesticide cost + pesticide application cost), *V* is the market value per production unit, *D* is the slope of the regression of *A. vulgare* density on percentage yield loss, and *K* is the reduction of injury due to treatment (i.e. pesticide efficacy, Manetti et al., 2009). The EIL is composed of both economic and biological parameters, which can be highly variable, and uncertain (Peterson and Hunt, 2003). Economic parameter *V* varies with changing economic conditions and management choices (Naranjo et al., 1996). To calculate EILs it were considered actual and average (2000/11) market value (US\$ Ton^{-1}) and production ($Ton\ ha^{-1}$) (ASAGIR, 2011; MINAGRI, 2011).

RESULTS AND DISCUSSION

Armadillidium vulgare injury on sunflower plants was done on cotyledons and hypocotyls, principally. The proportion of damages plants progress until 15-17 days after sowing. After that was not observed new damage.

In both 2009 and 2010, were observed a low proportion of plant with slight or moderate damage in all *A. vulgare* densities and these proportions were similar to control without any individuals ($p > 0.05$) (Table 1). In 2009, a higher proportion of severe damages were observed with 60 and 120 individuals m^{-2} respect to control ($p < 0.05$). While in 2010, this was observed only with 120 individuals m^{-2} (Table 1). In contrast Saluso (2004) reported that in soybean crop, with a higher plant density than sunflower, 160 individuals m^{-2} caused more severe damages respect to lower densities and control. Damages on cotyledons were similar between *A. vulgare* densities ($p > 0.05$) and differ respect to control ($p < 0.05$), except with 120 individuals m^{-2} which were similar to control in 2009 ($p < 0.05$). In both years, total damages were similar between all treatments ($p > 0.05$) and these differs respect to control ($p < 0.05$) (Table 1).

Table 1. Proportion of damage sunflower plants with different densities of *Armadillidium vulgare* in 2009 and 2010. S: slight, M: Moderate, Se: severe. Means in a column followed by the same letter are not statistically different (p> 0.05).

	Proportion of damaged plants (2009)					Proportion of damaged plants (2010)				
	Hypocotyl			Cotyledons	Total	Hypocotyl			Cotyledons	Total
Treatment	S	M	Se			S	M	Se		
Control (0 ind m^{-2})	0 a	0 a	0 b	0 b	0b	0 a	0 a	0 b	0 b	0 a
20 ind m^{-2} (1)	-	-	-	-	-	0 a	0 a	0.13 ab	0.37 a	0.50 b
40 ind m^{-2}	0.18 a	0.09 a	0.11 ab	0.33 a	0.71 a	0 a	0.08 a	0.10 ab	0.32 a	0.50 b
60 ind m^{-2}	0.03 a	0.03 a	0.22 a	0.46 a	0.74 a	0 a	0 a	0.15 ab	0.40 a	0.55 b
80 ind m^{-2}	0.08 a	0.15 a	0.15 ab	0.40 a	0.78 a	0 a	0 a	0.13 ab	0.32 a	0.45 b
120 ind m^{-2}	0.07 a	0.07 a	0.31 a	0.31 a	0.76 a	0 a	0 a	0.26 b	0.20 ab	0.46 b

[1]20 individuals m^{-2} in 2009 was omitted of the analysis because some replications were lost.

In 2009/2010 crop season, sunflower yield with 120 individuals m^{-2} was lower than yield with both 40 individuals m^{-2} and control ($p < 0.05$). In addition, was observed similar crop yield with 60, 80 and 120 individuals m^{-2} ($p > 0.05$) (Table 2). This could be related with relatively higher proportion of severe damages on hypocotyls observed whit these *A. vulgare* densities (Table 1). On the other hand, in 2010/2011 crop season, were not observed significantly differences in sunflower yield ($p = 0.39$).

Table 2. Means sunflower yield (± Standard Deviation) with different densities of *Armadillidium vulgare* in 2009/2010 and 2010/2011 crop seasons. Means in a column followed by the same letter are not statistically different (p> 0.05).

Treatment	Yield (g m^{-2})	
	2009/2010	2010/2011
Control (0 ind m^{-2})	356,23 (35,94) a	599,88 (79,99)
20 ind m^{-2} (1)	-	542,43 (152,51)
40 ind m^{-2}	333,34 (82,09) a	462,16 (110,27
60 ind m^{-2}	289,86 (76,52) ab	519,61 (154,93)
80 ind m^{-2}	298,26 (105,02) ab	566,08 (59,74)
120 ind m^{-2}	206,72 (108,06) b	460,47 (132,18)

[1]20 individuals m^{-2} in 2009 was omitted of the analysis because some replications were lost.

One of the fundamental concepts of IPM is that each pest species has a definable relationship in terms of damage to the plant host that it attacks. This relationship is often referred to as the damage curve, which is often determined relative to yield loss (Higley and Peterson, 1996). Only 2009/10 infestation data provided significant regression between density of *A. vulgare* and sunflower yield-loss (damage function) (Figure 1). The percentage yield loss–*A. vulgare* density relationship gave a positive linear yield function ($p < 0.05$). With this equation, an average of 1 individual of *A. vulgare* m^{-2} reduced the sunflower yield by 0.351%.

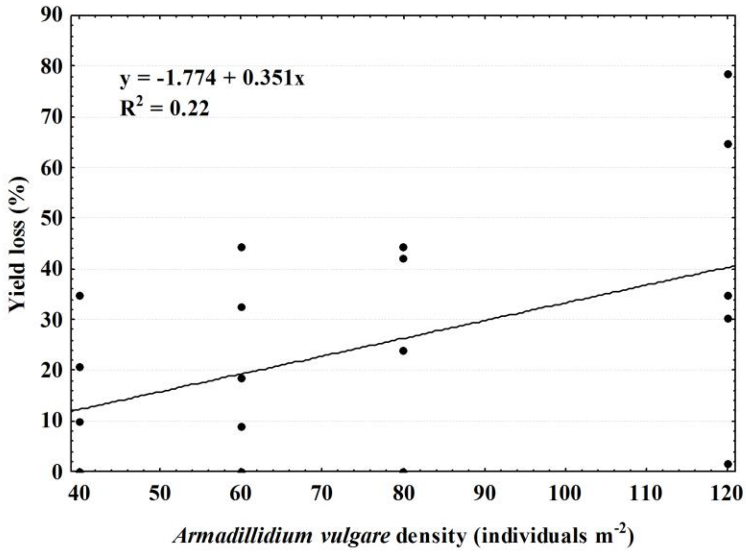

Fig. 1. Damage function of the Economic Injury Level of *Armadillidium vulgare* on sunflower.

Even if, it is the first source of information about damage curve of *A. vulgare* in the sunflower crop some considerations are necessary. Many factors can alter the relationship between yield and pest density resulting in a new damage curve (Higley and Peterson, 1996; Trumper, 2001). It is difficult to establish simple relationship between pest number and yield loss because these relationships are very influenced by environment (Higley and Peterson, 1996). In this study, we can fit a significant regression model only for one year of study. This indicates the variable nature in the relationship of sunflower yield loss and *A. vulgare* density. Additional efforts are necessary to achieve greater accuracy in the estimation of the damage curve of *A. vulgare* in the sunflower crop. However, the damage curve allows calculate EIL in different conditions.

A mathematical description for the damage curve is essential in estimating the *D* variable for EIL calculation. In this study the relationship between *A. vulgare* densities and sunflower yields lost was used to develop damage function and to generate EILs in relation to dynamic changes in sunflower prices and yield, control costs, and pest control efficacy (Trumper, 2001). Using Pedigo´s et al. (1986) model EILs were calculated for a wide range of reasonable scenarios (Table 3). Thus, the calculated range of EILs of *A. vulgare* on sunflower ranged from 13 to 95 individuals m^{-2} (Table 3). These values are lower than those obtained by Saluso (2004) on soybean crops. The author found that EIL ranged from 74 to 177 individuals m^{-2}. This crop is sown at higher plant densities and more individuals of *A. vulgare* m^{-2} are necessary to cause economic damage.

The EIL is an important conceptual and practical tool for decision making in IPM programs (Higley and Pedigo, 1996). The EIL values propose the *A. vulgare* densities that cause sufficient damage to justify treatment costs. Therefore, it is suggested that sunflower producers use pesticides only when the *A. vulgare* density reaches the EIL. This information may be considered by plantation managers as a first order guideline for pest management decision-making to reduce costs of pesticides use, and so increase profitability and conserve environmental quality.

Table 3. Economic Injury Levels of *Armadillidium vulgare* (expressed as individuals m^{-2}) on sunflower crop. C: control costs (pesticide cost + pesticide application cost; US\$ ha^{-1}), V: market value per production unit (US\$/Ton), K: reduction of injury due to treatment (i.e. pesticide efficacy).

			Price (US\$ Ton^{-1})			
			Mean (2001-2011) 135		Actual (2011) 260	
			Yield (Ton ha^{-1})			
			Mean (2001-2011) 1.69	Actual (2011) 2.35	Mean (2001-2011) 1.69	Actual (2011) 2.35
	C	K	NDEs			
4 kg ha^{-1} Carbaryl bait	26	50	65	47	34	24
		70	46	33	24	17
		90	36	26	19	14
3 kg ha^{-1} Carbaryl + Metaldehyde bait	25	50	62	45	32	23
		70	45	32	23	17
		90	35	25	18	13
4 kg ha^{-1} Carbaryl + Metaldehyde bait	32	50	80	57	41	30
		70	57	41	30	21
		90	45	32	23	17
5 kg ha^{-1} Carbaryl + Metaldehyde bait	38	50	95	68	49	36
		70	68	49	35	25
		90	53	38	27	20

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