Crop Protection 30 (2011) 1144–1148

Contents lists available at ScienceDirect

Crop Protection

journal homepage: www.elsevier.com/locate/cropro

Assessing yield losses caused by the harvester ant *Messor barbarus* (L.) in winter cereals

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ARTICLE INFO

Article history:
Received 8 October 2010
Received in revised form
9 May 2011
Accepted 10 May 2011

Keywords:
Yield loss at sowing
Yield loss at harvest
Damage
Nest density
Colony size
No-till

ABSTRACT

Harvester ants from the species *Messor barbarus* (L.) are important seed predators in semi-arid cereal fields of NE Spain, and can contribute substantially to weed control. However, occasionally they harvest newly sown crop seeds at sowing in autumn, or ripe cereal grains close to harvest in summer, causing yield losses.

A preliminary study was conducted in 34 commercial winter cereal fields to measure yield loss, and to identify factors that influence it. The area affected by ants was measured ten days prior to the anticipated harvest date. Ant colony size, nest density, crop height, weed densities and temperatures at sowing were assessed.

At sowing, harvester ants did not cause yield losses (0.2% of potential yield on average). At harvest, yield losses were generally low as well (0.6%) although occasionally higher losses were recorded (max. 9.2%). Yield losses significantly increased with increasing nest density, nest size and with number of years of no-till. The results of this study show that in 2009 yield losses caused by *M. barbarus* were insignificant and more than offset by the benefits provided by the destruction of weed seeds.

1. Introduction

Messor barbarus (L.) is one of the main species of harvester ants in the semi-arid region of north-eastern Spain. It plays a role in weed control because it collects and destroys a large proportion of the newly shed weed seeds, thus limiting the build up of weed populations (Atanackovic, 2010; Baraibar et al., 2009). However, under certain circumstances and in some years, farmers report yield losses caused by ants. Here, we investigated if and when harvester ant-induced yield losses occur and estimated their magnitude.

Damage can occur at sowing in late autumn or close to harvest in summer. Harvester ants can collect crop seeds that are superficially drilled or simply scattered over the soil surface at sowing (Campbell, 1982). At harvest, harvester ants cut grains or entire ears straight from the cereal plants.

It is likely that the density of harvester ants, which can be estimated by nest density and colony size, will influence yield losses. Nest density seems to be influenced by the number of years that a field has not been tilled (Baraibar et al., 2010). In the last 25 years, many farmers in the region have adopted no-till or minimum till in order to save costs, increase water use efficiency and improve yield of rainfed cereals (Cantero-Martínez et al., 2007). Harvester ants are favored by these techniques, reaching high densities and large colony sizes (Baraibar et al., 2009). Big nests have more ants and, thus, need more food. Furthermore, large colonies have a higher proportion of workers devoted to foraging than smaller colonies (Tschinkel, 1998), and more “soldiers”, which are better able to harvest crop seeds (Baraibar, personal observation).

Winter cereals in north-eastern Spain are usually sown at the beginning of November, when temperatures start to decrease and relative humidity is high (Servei Meteorològic de Catalunya, 1971–2000). The combination of low temperatures and high relative humidity leads colonies of harvester ants to close down for winter hibernation (Azcarate et al., 2007). The minimum threshold temperature reported for *M. barbarus* activity is 9 °C (Azcarate et al., 2007). However, occasionally temperatures remain high deep into November, or temporally rise again, causing a burst in harvester ant activity, which may result in the harvesting of newly sown crop seeds. In addition, seeds that are not buried at drilling are more likely to be harvested, because, in general, seed predators do not dig for seeds but remove seeds available on the soil surface (Hulme, 1994).

Cereal type (wheat, barley, triticale) and variety may differ in the rate of maturation and in architecture, which may influence the

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0261-2194/$ – see front matter © 2011 Elsevier Ltd. All rights reserved.
doi:10.1016/j.cropro.2011.05.010

timing and the ease with which ants gain access to the grains and can cut ears off the plant. Architectural differences could include, for example, hairs on the stem, the height at which the ears are formed, or the thickness of the stem. In certain years, densities of alternative seed sources at harvest, in particular weed seeds, may be insufficient to satisfy the needs of all colonies. In this case, harvester ants may engage in the more energy-consuming strategy of collecting crop seeds off the plant.

This study is a first attempt to quantify crop losses caused by granivorous ants both at sowing and at harvest. In addition, the relationship between some of the factors that could influence yield losses, namely nest density and colony size, number of years of no-till, date of sowing and harvest, crop height, temperatures after sowing and weed abundances were explored.

2. Materials and methods

2.1. Experimental site and design

This research took place in 2009 in the area of Agramunt, a village in semi-arid north-eastern Spain. Long-term average temperature is 13.9 °C and average rainfall is 428 mm, concentrated in spring and autumn (Servei Meteorològic de Catalunya, 1971–2000). Yield loss was assessed in 34 commercial cereal fields that had been sown to cereals between 2 October and 25 November 2008. Twenty nine fields had been planted with barley (*Hordeum vulgare* L.), four with wheat (*Triticum aestivum* L.) and one with triticale (×*Triticosecale* Wittm.). Twenty eight of the fields were managed without tillage for periods between 1 and 25 years, and 6 with minimum tillage. Minimum tillage included a tillage operation at the beginning of autumn, prior to sowing; working depth of 15–20 cm. Preliminary analysis showed that tillage did not directly affect yield losses caused by ants, neither at sowing nor at harvest. Therefore, data from minimally tilled and no-till fields were combined and jointly analyzed.

In each field, an area of 50 m × 50 m was marked permanently, and used to assess 1) area affected by ants, 2) ant colony size, 3) ant nest density, 4) crop height and 5) weed density.

Yield loss was assessed between 12 and 22 June 2009, ten days before the anticipated crop harvest (22–29 June). In three fields, harvest did not occur on the anticipated harvest date, but two weeks later, namely on 6 (one field) and 12 July (two fields). Therefore, in these three fields yield loss was assessed twice; prior to the anticipated and the real harvest. Damage assessed at the later date was used in the analyses. The surface area affected by the ants was measured for ten randomly selected nests within the 50 m × 50 m area. The area affected by each nest at sowing, A_s, was distinguished from the area affected at harvest, A_h, by the visible symptoms; seeds harvested at sowing resulted in an area surrounding the nest that was void of crop, while damage at harvest was characterized by the removal of ears from crop rows at and adjacent to the nest. Causes other than ants, such as fatal germination or seedling mortality due to insects (*e.g.* the beetle *Zabrus tenebroides* (Goeze)), cannot completely be excluded as causes for crop failure at sowing. However, the spatial coincidence with ant nest presence strongly suggests a causal relationship. The number of rows and the length of the row(s) affected were measured, and converted to calculate the average area affected, $\overline{A}_s$ and $\overline{A}_h$ (ha nest^{-1}).

The size of the ten selected *M. barbarus* colonies was estimated, using a subjective scale that ranged from 1 (small) to 5 (large), based on the area occupied by the colony, the number of entrances, worker size and the number of active ants. The average nest size, $\overline{S}$, was calculated.

After crop harvest, all *M. barbarus* nests in the 50 m × 50 m area were counted, using a grid spaced 10 m apart, and marked with spray-paint to prevent double counting. Counts were converted to numbers of nests per hectare, N.

The height at which ears were formed was measured next to the ten nests, and averaged to produce the average crop height, $\overline{H}$.

Weed densities were assessed in 30 random locations within the 50 m × 50 m area in May 2009 by identifying and counting all weeds along 1 m between two cereal rows. Weed counts were averaged and converted to numbers per square meter, $\overline{W}$ (m^{-2}).

The number of days (T_d) and the number of hours (T_h) with temperatures above 9 °C after sowing were determined, using hourly and average daily temperatures (°C) from October to December 2009 for Tàrrega, 17 km away from the experimental fields (Servei Meteorològic de Catalunya, September 2010).

Finally, the farmers provided information on crop type, crop variety, sowing date, sowing depth (D), number of years of no-till (NT), and yield (Y).

2.2. Data analysis

Damage was expressed as the yield loss (YL), caused by harvester ants, and was calculated as:

$$YL = \overline{A} \times N \times Y \left[\text{kg ha}^{-1}\right]$$

with Y, the crop yield obtained in that field (kg ha^{-1}), as provided by the farmer.

Generalized linear regression (Genstat 12) was used to relate YL_s to the explanatory variables N, $\overline{S}$, crop, NT, T_d and T_h, and D; and YL_h to the explanatory variables N, $\overline{S}$, crop, NT, $\overline{H}$, Y and $\overline{W}$. First, the best model(s) explaining YL_s and YL_h were selected based on all subset regressions (procedure RSEARCH), using R^2_{adj}, Cp and AIC as selection criterions. Next, the final model was selected based on R^2_{adj} and significance of the GLM (GLM procedure, log-link, free dispersion).

3. Results

3.1. Yield loss at sowing

Averaged over all fields, yield loss at sowing, YL_s, was 6.7 kg ha^{-1}, or 0.2% of potential yield. In most of the fields, YL_s was negligible (<18 kg ha^{-1} or 0.6%) and only in two fields was YL_s higher, namely 46 and 49 kg ha^{-1} or 1.6%. Sixty-six percent of the nests did not cause any yield loss at sowing while 32.9% affected an area smaller than 0.5 m^2 (Fig. 1, black bar).

Yield loss at sowing was best described by the variables: nest density, N, average nest size, $\overline{S}$, and the number of years of no-till NT

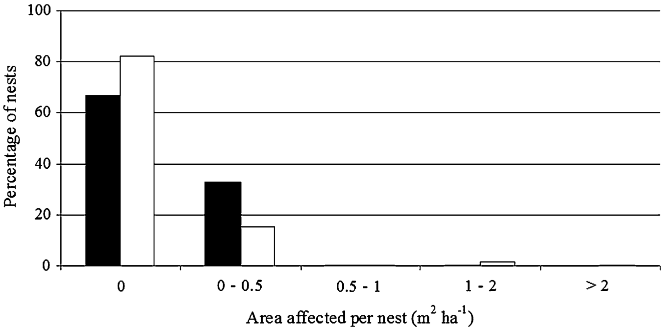

Fig. 1. Frequency distribution of nests in 34 fields (n = 10 × 34) according to area affected per nest (m^2 ha^{-1}) at sowing (black bar) and close to harvest (white bar).

(Table 1). Yield loss at sowing increased with increasing nest density, nest size and number of years of no-till. The model explained 73.5% of the variation. The regression equation to predict YL_s is as follows:

$$\mathrm{Log}_{10}(YL_s) = -3.56 + 0.003\,N + 1.43\ \overline{S} + 0.06\,NT$$

3.2. Yield loss close to harvest

Averaged over all fields, yield loss at harvest, YL_h, was 18.5 kg ha^{-1} or 0.6%. In most fields, YL_h was negligible, namely <30 kg ha^{-1}. Only in two fields losses were higher, namely 238 and 274 kg ha^{-1}, representing 8 and 9.2% of the average yield, respectively. Eighty-two percent of the nests did not cause any yield loss at harvest (Fig. 1, white bar).

There were a number of competing models that correctly described YL_h.. All models included N, $\overline{S}$ and NT. More elaborate models, which included crop height, $\overline{H}$, and yield, Y, had a minimal AIC and a maximum R^2_{adj}. However, we opted for a smaller model including N, $\overline{S}$, and NT, because the addition of H or Y did not significantly improve the regression (Table 2). Yield loss at harvest increased with increasing nest density, nest size and number of years of no-till (Fig. 2). The model explained 64.8% of the variation. The regression equation to predict YL_h is as follows:

$$\mathrm{Log}_{10}(YL_h) = -8.67 + 0.007\,N + 2.63\ \overline{S} + 0.08\,NT$$

Yield loss at harvest was more than three times higher in the three fields that were harvested late (60.11 ± 68.57 ($\bar{x}$ ± sem)) than in fields harvested earlier. This was mainly caused by a large increase in the level of damage in one field.

4. Discussion

In general, yield losses by harvester ants were small, and economically insignificant.

Losses at sowing were affected mainly by harvester nest density, N, average nest size, $\overline{S}$, and number of years of no-till, NT. The combination of N and $\overline{S}$ can be regarded as an estimate of harvester ant density. In the case of the fire ant, *Solenopsis invicta* Buren, which is known to cause damage to crops such as potatoes, soybeans, corn and sorghum, in the United States, Australia and some Asian countries, correlations were found between crop losses and the number of ants caught per bait trap (Adams et al., 1988), and colony size (Drees et al., 1991). Nest density of *M. barbarus* increases with increasing number of years of no-till, reaching a maximum after 10–12 years (Baraibar et al., 2010). The reason for the growth in the number of colonies is probably the lack of soil disturbances. Soil disturbances destroy the shallow nests of young colonies, destroy the nest entrances of older colonies, force workers to allocate time to reconstruction rather than gathering seeds, and bury surface seeds, which are no longer available to the ants. In soils without tillage, harvester ant colonies may have higher survival and growth rates. Foraging efficiency is related to ant nest density

Table 1
Generalized linear regression analysis (GLM) on yield loss at sowing, YL_s, caused by harvester ants *Messor barbarus*, as influenced by nest density (N), average nest size ($\overline{S}$) and number of years of no-till (NT).

	Df	Mean Deviance	Deviance ratio	*P* value
Nest density (N)	1	180.9	56.43	<0.001
Nest size ($\overline{S}$)	1	87.45	27.28	<0.001
Years of no-till (NT)	1	17.09	5.33	0.029
Residual	28	3.21		
Total	31	12.1		

Table 2
Generalized linear regression analysis (GLM) on yield loss close to harvest, YL_h, caused by harvester ants *Messor barbarus*, as influenced by nest density (N), average nest size ($\overline{S}$) and number of years of no-till (NT).

	Df	Mean Deviance	Deviance ratio	*P* value
Nest density (N)	1	1238.52	166.6	<0.001
Nest size ($\overline{S}$)	1	1049.49	141.17	<0.001
Years of no-till (NT)	1	32.03	4.31	0.047
Residual	28	7.43		
Total	31	81.55		

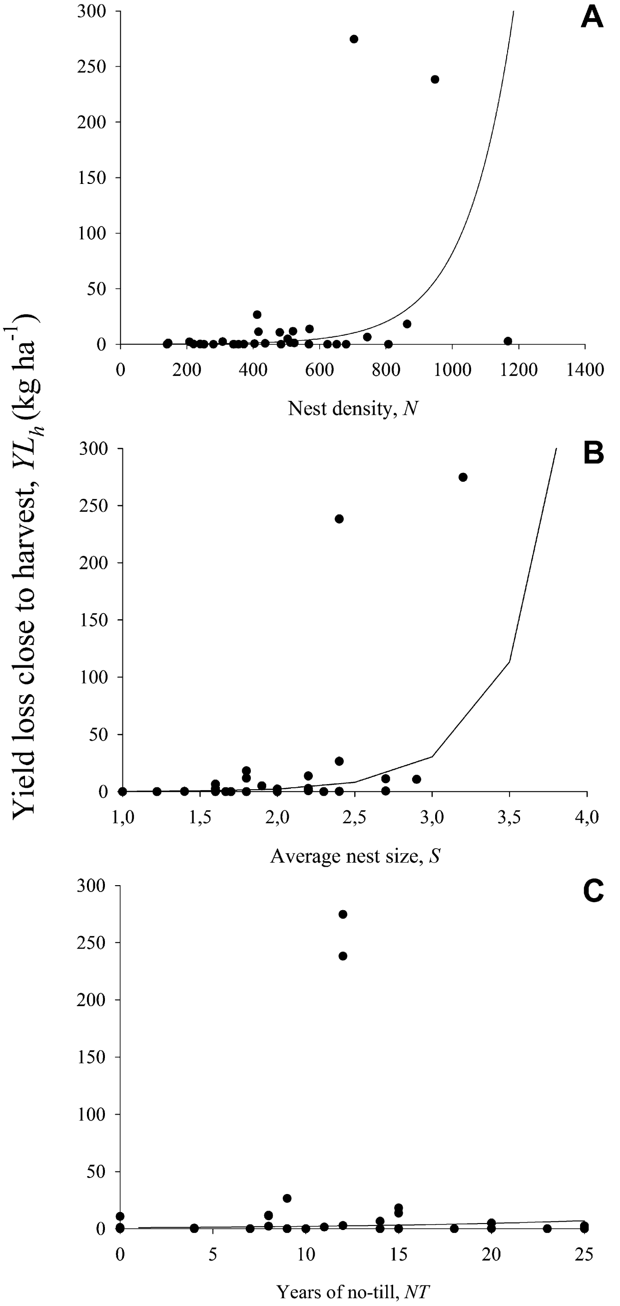

Fig. 2. Regression lines and observed yield losses close to harvest, YL_h, as a function of nest density, N (A), average nest size, $\overline{S}$, (B), and years of no-till, NT (C).

(Baraibar et al., 2011), and it is, therefore, likely that seed consumption will be higher in the case of high ant densities and large colonies.

Contrary to expectations, T_d and T_h, the number of days or hours after sowing with temperatures >9 °C, did not contribute to explaining variability in yield losses caused by harvester ants at sowing, YL_s. Apparently, the duration of the period with temperatures >9 °C was unimportant. A single day with some hours with temperatures >9 °C, which occurred in all fields, seems to be sufficient to induce damage. This suggests that the ants do not require much time to gather the seeds.

Seed burial usually prevents seed harvesting and consumption by predators (Drees et al., 1991; Brown et al., 2003). Superficial drilling could put seeds at risk of exposure. However, during model selection, sowing depth was not selected as an explanatory variable. It is possible that the seeding depth provided by the farmers was inaccurate and that, in reality, seeds were more superficially planted, due to soil compaction, presence of stones, dense crop stubble, etc. Another possibility is that, although the seeds were delivered at the required depth, the seeding furrow did not close after seeding, resulting in exposure to harvester ants.

Yield losses caused by harvester ants close to crop harvest were explained by nest density, N, average colony size, $\overline{S}$ and number of years of no-till, NT. High nest density may increase competition among colonies for food, forcing colonies to harvest seeds off the crop. On average, large nests (category 5) caused more damage than small nests. *M. barbarus* has three castes of workers, namely *minor*, *media* and *major*, which usually perform different tasks within the colony. For *Pogonomyrmex badius* (Latreille), another species of granivorous ants, Tschinkel (1998) reported an increase in the number and size of *major* workers as the colony grows. Because only the mandibles of these big workers are strong enough to successfully cut the ears of cereals (Baraibar, personal observation), this could provide a plausible explanation for the fact that colony size is related to yield losses close to harvest.

In the three fields that were harvested late, yield loss tended to be higher than in remaining fields that were harvested two weeks earlier. Possible explanations include 1) a longer exposure period of the cereals to the ants, and 2) more mature cereal grains. In June and July, colonies of *Messor* spp. have a high production of new workers, which can lead to a rapid increase in the foraging activity (Díaz, 1992). A delay in harvest date would allow these ever increasing numbers time to increase harvest rate. Similar results were obtained for the fire ant, *S. invicta*. Longer exposure increased the proportion of wheat, corn and sorghum seeds damaged in laboratory experiments (Morrison et al., 1997). The spikes of fully mature and dry crops may be easier to bite through and harvest. However, proof for either hypotheses is currently lacking.

Most seeds of important weeds in semi-arid winter cereals, such as *Lolium rigidum* G., *Bromus diandrus* Roth and *Papaver rhoeas* L., are shed prior to harvest (Atanackovic, 2010). The availability of these weed seeds on the soil surface was expected to reduce yield loss close to harvest because climbing cereal plants is much more energy and time consuming than foraging seeds on the soil surface (Azcarate et al., 2005; Heredia and Detrain, 2005). However, there was no relationship between weed density and the yield loss caused by ants at harvest. We realize that weed density alone may not suffice as a proxy for seed availability. Weed species distribution on the field may have influenced weed seed availability close to the ant nests and determined the need to harvest crop seeds. Burial of the smallest seed species may have reduced seed availability on the soil surface and may have increased yield loss. Therefore, it would have been better to quantify the number of weed seeds available to ants prior to harvest (*e.g.*, Westerman et al., 2003; Atanackovic, 2010).

We could not confirm that wheat was more prone to damage by harvester ants than barley, as claimed by local farmers, because of insufficient wheat fields in our survey. Nor could we confirm if differences in yield losses were caused by crop varieties. Expanding the survey, to include replications of the various crops and cultivars, could also be a useful way to investigate whether structural differences or differences in the rate of maturation influence the level of crop damage caused by harvester ants.

There are various ways to prevent ant-induced yield losses. Early crop harvest could in some cases reduce yield loss, although this recommendation is based on the fate of a single field only. There was no evidence for the hypothesis that high temperatures in autumn increased yield losses at sowing. Nevertheless, fields sown in October or the first half of November tended to have higher yield losses than fields sown during the second half of November. So, delaying sowing until temperature drops below 9 °C could help to prevent yield losses at sowing. Both recommendations need to be tested first.

A third option involves reducing harvester ant population density. Spraying insecticides, to reduce harvester ant populations, is not suitable because it would only eliminate worker ants that are on the soil surface. Spraying does not affect the queen, which is buried deep in the colony, and which is responsible for the survival and growth of the colony (Cerdan, 1989). Spraying might be effective if it is done on the day of the release of the reproductives, which are released yearly following the first autumn rains. Killing new queens would reduce the density of nests. However, the prediction of the exact day the flights take place is difficult, hence, spraying cannot be timed. The use of ant bait insecticides could be an alternative option to control ants. Worker ants take the bait to the nest and feed the queen; the death of the queen causes the death of the colony. Cereal and product prices largely determine the cost-effectiveness of this treatment. The estimated cost of an ant bait application is currently justified in fields with more than 150 kg ha^{-1} of yield loss. However, no chemical products are registered against harvester ants in grain crops. A more readily adoptable option to decrease harvester ant density is a year of intense cultivation, because soil disturbance reduces the survival chances of ants nests, in particular the shallow colonies of young nests.

In summary, this study indicated that yield losses caused by the harvester ant *M. barbarus* were generally low in 2009. Harvester ants contribute to weed control in semi-arid cereal systems (Baraibar et al., 2009). At least in 2009, yield losses caused by harvester ants were more than offset by the benefits provided by the destruction of weed seeds.

Acknowledgments

We gratefully acknowledge the field assistance of Valentina Atanackovic, Addy Laura Garcia, Jordi Recasens, Sergi Royan and Joel Torra. We would also like to thank Jaume Gregori for initiating contact with the farmers and for his assistance during the investigation. Finally, we'd like to thank all the farmers who generously allowed us to use their cereal fields, for their patience and hospitability and two anonymous reviewers for their comments and suggestions for improvement. Financial support was provided by Generalitat de Catalunya (PhD grants, F.I.) with the support of the EU Social Fund, Ramón y Cajal grant and Ministerio de Educación y Ciencia (Project AGL 2007-60828).

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