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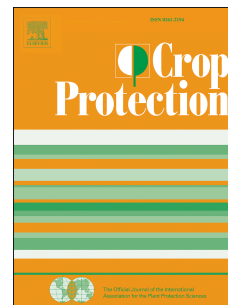


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1 **Editorial - Impact assessment, ecology and management of animal pests affecting**
2 **field crop establishment: An introduction to the special issue**

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6 **Keywords:** bird damage, emergence failure, post-emergence damage, seed damage,
7 seed predation, seedling damage, seedling losses

8 **1. The crop establishment phase**

9 Crop establishment is an early phase that consists of three sub-phases: sowing to seed
10 germination, seed germination to seedling emergence, and seedling emergence to initial
11 competition among young plants (Aubertot et al., 2020; **Figure 1**). The initial seed and
12 seedling vigor (i.e. the speed of seed germination and seedling emergence; Maguire,
13 (1962)) are a key indicators that determine a rapid, uniform and robust crop
14 establishment across diverse environmental conditions (Finch-Savage and Bassel, 2016;
15 Maguire, 1962).

16 The quality of field crop establishment can be characterized by the rate of healthy
17 looking young plants compared with the sowing density (Lamichhane et al., 2020b). This
18 means that only a high percentage of final emergence is not sufficient for a crop to
19 successfully establish as a non-optimal initial vigor will result in poor growth with
20 stunted young plants. Resource use efficiency and crop yield depend on successful plant
21 establishment in the field. This is especially true for crops that are not able to
22 compensate pre- and post-emergence damage and/or losses due to several factors
23 **(Table 1)**.

24 Several biotic (Firake et al., 2016; McKee et al., 2020; Rojas et al., 2016; You and Barbetti,
25 2017) and abiotic (Bybordi and Tabatabaei, 2009; Wijewardana et al., 2019) factors may
26 lead to a poor quality of crop establishment (**Figure 2**). This has several direct (e.g. yield
27 losses, additional production costs due to seed purchase and resowing etc.) and indirect
28 (e.g. weed development and increased seedbank that leads to heightened management
29 costs) consequences for growers (Lamichhane et al., 2018).

30 Crop establishment is affected by five major groups of drivers and their interactions
31 namely seed and seedling characteristics, seedbed components (physical, chemical and
32 biological), weather, cropping systems (Lamichhane et al., 2018), and animal pests
33 coming from outside the seedbed (Lamichhane et al., 2020b). The latter have been
34 increasingly reported to cause post-emergence damage of field crops (Dimitri et al.,
35 2012; Firake et al., 2016; Lamichhane, 2021; McKee et al., 2020; Nasu and Matsuda,
36 1976). A successful management of animal pests affecting crop establishment requires a
37 systems-level approach that combines a range of disciplines including Agronomy,
38 Biology and Ecology.

39

40

41 **2. Key animal pests affecting the crop establishment phase**

42 Vertebrate (e.g. birds, mammals, rodents etc.) and invertebrate (e.g. flea beetles, slugs,
43 maggots, wireworms) pests cause damage to germinating seeds and emerging or
44 emerged seedlings (**Figures 3-5**). However, the type and extent of their damage depend
45 on the characteristics related to the plot, field, or landscape. Characteristics related to
46 the plot include the plot's size, crop species, sowing date, and tillage type; those related
47 to the field include the extent of crop diversification and presence or absence of natural
48 or semi-natural habitats; and those related to the landscape include residential areas,
49 forests, and annual vegetations.

50 **3. Introduction to the special issue: Impact assessment, ecology and** 51 **management of animal pests affecting field crop establishment**

52 This special issue focuses on vertebrate and invertebrate pests affecting the crop
53 establishment phase. These pests may cause partial or complete crop establishment
54 failure with a huge economic impact for growers. Understanding the biology, ecology
55 and population dynamics of these animal pests and their impact on the establishment
56 quality of a given crop is a first step toward the development of sustainable crop
57 protection measures that can be embedded into an integrated pest management (IPM)
58 framework. The special issue includes seven research articles and one perspective
59 paper, for a total of eight papers, which are grouped into three sections. The following
60 are representative summaries of the articles gathered in this issue.

61 3.1. Damage assessment, identification and risk predictions of animal pests 62 affecting crop establishment

63 Post-emergence seedling damage due to birds has become the most important economic
64 problem for sunflower growers in France. Although severe losses of sunflower seedlings
65 have been increasingly reported by growers across the country, no study attempted to
66 date to quantify these losses. Sausse et al. (2021b), conducted a three-year
67 observational study across 206 sunflower fields in two major sunflower production
68 basins of France, and quantified the rate of post-emergence seedling damage. The
69 authors found that 98% of the sunflower fields showed partial or total seedling damage
70 symptoms attributable to birds. In particular, 10% of the surveyed fields were
71 particularly affected with over 20% of seedlings completely destroyed. This damage
72 results either in an increased production cost (in the case of resowing) or in significant
73 production losses when no resowings are performed.

74 Wireworms represent one of the most important soil-dwelling pests from an economic
75 point of view. These pests cause severe damage on crops, especially at the crop
76 establishment phase. The severity of damage due to wireworms has been reported to
77 increase under no-till systems although there is no consensus in the literature in this
78 regard. Furlan et al. (2021b) investigated the effect of conventional versus no-tillage
79 practices on the population dynamics of wireworms and the associated damage in the
80 early growth stages of maize crops over a six-year study period (2011-2016). The
81 authors did not find any significant effect of tillage versus no-till practices on the

82 population density of these pests or the associated damage to maize crops at the crop
83 establishment phase. These results are encouraging for an increased adoption of no-till
84 practices, which provide numerous environmental benefits including reduced soil
85 erosion.

86 Mice cause significant damage to crops worldwide by digging up and consuming newly
87 planted seeds, or by cutting seedlings and stems, and feeding on developing grains.
88 Under favorable conditions, mice can rapidly increase in abundance to form mouse
89 plagues. Forecasting mice population dynamics can assist management to keep this pest
90 species at tolerable densities. This is important for preventative management of the pest
91 that is sustainable in the long-term compared with reactive management, the latter
92 being most often adopted to date. Wang et al. (2021) developed an iterative modeling
93 approach, involving statistical inference and forecasting data, to predict the population
94 dynamics of the striped field mouse (*Apodemus agrarius*), an indigenous rodent, in a
95 cropland. This approach allowed to understand the effects of environmental variables
96 (rain, temperature, and crop types) on the pest population dynamics, which, in turn,
97 helped predict population outbreaks at the site level several months before their
98 occurrence. The forecasting approach used by the authors can contribute to planning
99 and deployment of *A. agrarius* management measures and to avoid crop damage.

100 3.2. Management of animal pests affecting crop establishment

101 Birds' damage to sunflower represents an important problem for growers as it often
102 leads to severe economic losses. No effective management measures exist to date to
103 reduce such damage. Werrell et al. (2021) propose a Sonic Net that broadcasts synthetic
104 sounds at frequencies which purportedly mask or block birds' normal communications.
105 In this way, birds are deprived of essential aural information; they vacate the impacted
106 area for more secure locations beyond the reach of Sonic Net. By testing this device
107 through basic small-plot field experiments, the authors demonstrated the effectiveness
108 of the sonic net that reduced damage to sunflowers by 23% to 64% at maturity,
109 depending on field locations. The authors predict that the effect of the Sonic Net
110 treatment may be greater in other crop phases and types, such as in the establishment
111 phase or ground cover crops. Indeed, a relative lack of tall, three-dimensional
112 vegetational structure at the crop establishment phase may allow a more effective
113 spread of the Sonic Net sound offering fewer physical refugia for birds to lower their
114 perceived predation risk. Future studies should test the efficacy of this device on other
115 crops and specifically at the crop establishment phase.

116 Feral or wild pigs represent one of the most important invasive species that cause
117 severe economic crop losses worldwide. These animal pests may attack a large number
118 of crop species and the crop establishment phase is particularly vulnerable to their
119 attacks. More specifically to maize, feral pigs' damage to this crop mainly occurs
120 immediately following planting as these pests consume the freshly planted and
121 germinated seeds. Protecting the maize seeds or seedlings from feral pigs is important to
122 ensure a good quality of maize establishment. Snow et al. (2021) propose an
123 anthraquinone repellent seed treatment to limit seed and seedling damage due to feral
124 pigs. The authors showed that the repellency rate was affected by the concentration of
125 anthraquinone used and that treating the maize seed with 3% anthraquinone resulted in

126 the greatest reduction in damage. Testing of this method under a wide range of field
127 conditions and monitoring for the damage rate as well as the duration of protection
128 offered by this seed treatment method may provide further insights into the usefulness
129 of this method for growers to limit feral pig damage to maize. Nevertheless, unlike in the
130 US, the use of this product is forbidden in many countries including those of the
131 European Union.

132 Identification of the potential risk factors triggering animal pest damage to maize
133 seedlings and an accurate assessment of seedling losses represent the first step towards
134 integrated management of animal pests affecting the crop establishment phase. Furlan
135 et al. (2021a) through a long-term field survey, identified plant-attacking bird species,
136 agronomic characteristics, cultural practices, and landscape variables, such as the
137 presence of roosting areas. The authors determined that corvids were the most
138 important animal pests affecting maize crop establishment and that no-till practice
139 increased the damage severity compared with minimum and conventional tillage
140 systems. By using a multifactorial model, they highlighted that the presence of roosting
141 areas around the field plots was the most important risk factor that increased damage
142 risk up to five-fold. Seed coatings using chemical (methiocarb and ziram) and biological
143 (ScudoSeed® and Eurodif®) bird repellents effectively reduced the risk of corvid
144 damage to maize seedlings. Although the biological bird repellents were less effective
145 than their chemical counterparts in reducing seedling damage due to corvids, the former
146 kept the damage below the 15% threshold level. The authors conclude that integration
147 of biological bird repellents into IPM principles may result a viable option for growers to
148 limit corvids' damage to maize seedlings under high risk situations.

149 Vegetation management can be an important agronomic lever to reduce seedling
150 damage due to animal pests. Damage to maize seedlings by rodents, birds and insects,
151 such as stem-cutting termites, represents an important production constraint for
152 growers in central Cameroon. Norgrove (2021) investigated the potential effect of
153 different vegetation management techniques, namely chemical vs. manual weed
154 management and mulching vs. removal of vegetation residues through burning, on
155 maize seedling damage by these animal pests. The author showed that the presence or
156 absence of vegetation cover influenced different types of animal pests affecting maize
157 establishment. Seedling damage due to termites significantly increased in the absence of
158 vegetation while the damage due to birds markedly decreased in the same situation. The
159 removal of vegetation, which represents food sources for insects, via chemical weeding
160 or burning, was the key reason triggering insect attacks to living plants. This emphasizes
161 the importance of vegetation cover, including the presence of weed flora, in natural pest
162 regulations via an improved food source provisioning.

163 3.3. Challenges and opportunities for the management of animal pests affecting 164 crop establishment

165 Bird damage to crops in general and that at the crop establishment phase, in particular,
166 has become an important problem for growers. While severe bird damage at the
167 maturity phase occurs in North and South America, bird damage has become an
168 emerging problem at the establishment phase of spring-sown crops in France and
169 other European countries. However, crop losses due to birds have drawn only little

170 attention from the policy side resulting in poor research in these countries. As a
171 consequence, limited bird management tools have been developed and tested to date.
172 This has led to an impasse where the economic sustainability of growing spring crops
173 has been increasingly challenged. Faced with this uncertainty, growers tend to partially
174 or completely abandon crops such as sunflower from their cropping systems by replacing
175 them with other crops that are less likely to suffer bird damage. Sausse et al. (2021a)
176 discuss key contemporary challenges and opportunities for the management of bird
177 damage to crops. The authors highlight the need to adopt data intensive and multiscale
178 approaches to develop effective solutions for bird management and call for networking
179 to tackle this issue.

180 **4. Conclusions and perspectives**

181 Damage by animal pests at the crop establishment phase represents an important
182 problem for growers although the frequency and intensity of the damage may widely
183 vary in space and time. More specifically to arable crops, seed and seedling damage due
184 to animal pests has become an emerging problem for some crops such as sunflower,
185 maize, and soybean. However, the solution to this problem, especially that due to birds,
186 is increasingly difficult due to a number of issues as highlighted by Sausse et al. (2021a).
187 In addition, because many bird species provide both ecosystem services and disservices,
188 it is difficult to consider them only as « a pest », which further complicates their
189 management. For example, vertebrate pests such as birds and bats act as natural
190 predators of several crop pests (Sow et al., 2020).

191 Research and policy should come together with an increasing effort on networking at
192 local, regional, national and international levels. This will help in developing sustainable
193 management solutions that can limit animal pests' damage at the crop establishment
194 phase. More specifically to research, three key priorities can be identified for future: i)
195 an economic estimation of yield losses in monetary terms due to animal pests' damage
196 at the crop establishment phase; ii) an increased effort on the development and testing
197 of methods and/or tools and their robust economic analysis in terms of cost-
198 effectiveness; and iii) a larger scale testing of the effectiveness of newly developed tools
199 and/or methods, especially when they are used in combination with other management
200 strategies, as part of IPM.

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Table 1. Ability of field crops to compensate pre- and post-emergence losses and potential correlation between the quality of field crop establishment and yield

Crop type	Crop	Pre- & post-emergence losses compensation ability [#]	Compensation method	Potential correlation between crop establishment quality and yield*	References
Straw cereals	Barley	Yes	Tillering	No	del Moral and del Moral (1995)
	Oat	Yes	Tillering	No	Peltonen-Sainio and Järvinen (1995)
	Wheat	Yes	Tillering	No	Abati et al. (2017)
	Sorghum	Yes	Tillering	No	Maranville and Clegg (1977)
	Maize	No	Nil	Often positive [¶]	Liu et al. (2004)
	Rice	Yes	Tillering	No	Fageria (2007)
Pulse crops	Common bean	Yes	SDG, IG, B	No	De Ron et al. (2016); Raveneau et al. (2011)
	Pea	Yes	SDG, IG, B	No	Gan et al. (2002); Raveneau et al. (2011)
	Lentil	Yes	SDG, IG, B	No	Siddique et al. (1998)
	Chickpea	Yes	SDG, IG, B	No	(Gan et al., 2002)
	Faba bean	Yes	SDG, IG, B	No	López-Bellido et al. (2005)
Oleaginous crops	Sunflower	No	Nil	Often positive [¶]	McMaster et al. (2012)
	Oilseed rape	Yes	Branching	No	Hossain et al. (2019)
	Soybean	Yes	SDG, IG, B	No	Lamichhane et al. (2020a)
Root and tuber crops	Sugar beet	No	Nil	Often positive [¶]	Boiffin et al. (1992); Souty and Rode (1993)
	Potato	Yes	Branching	No	Vander Zaag et al. (1990)
Cover crops	Asteraceae, Brassicaceae, Fabaceae, Hydrophyllaceae, Poaceae, Polygonaceae	Most of them yes	SDG, IG, B	NA	Baligar and Fageria (2007); Huang et al. (2021); Marshall and Lewis (2004); Tridevi et al. (2015)

SDG: Semi-determinate growth; IG: indeterminate growth; B: branching; NA: not applicable; [#]Dependent on crop species and growth conditions

*The correlation depends on several factors including water availability, soil fertility, maturity rating, planting date and row spacing. A high heterogeneity in emergence date is detrimental to yield for certain crops as plants emerging late relative to neighboring plants provided reduced yield.

†When the number of individuals per area is increased beyond the optimum plant density, there is a series of consequences that are detrimental to yield

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Table 2. A visual diagnostic key describing major causes affecting crop establishment and descriptions of their symptoms/ characteristics

Sub-phase	Symptoms or characteristics		Causes of no crop establishment	References	
Sowing - seed germination	Seeds fail to germinate (pre-germination)	Absence of the intact seed or presence of seed parts	No presence of seed or seed parts	Technical problem of sowing or predation of seeds by pests*	Carabajal-Capitán et al. (2021); Tschumi et al. (2018)
			Outer seed coat altered, presence of empty seed coat	Damage caused by granivores (e.g. slugs, earthworms or rodents)	Carabajal-Capitán et al. (2021); Tschumi et al. (2018)
		Intact seed content but no germination	Abiotic stress (heat water or mechanical) or dormancy problem or seed death	Lamichhane and Aubertot (2021)	
Seed germination - seedling emergence	Seedlings fail to emerge (pre-emergence)	Presence of non-germinated and germinated seeds	Rotten seed content and no germination	Pre-emergence damping-off (seed- and soil-borne pathogens)	You and Barbetti (2017)
			Presence of holes or larvae in or around seeds	Soil-borne pests (e.g. seed maggots, wireworms, symphylans, millipedes)	Ebregt et al. (2005)
			Occurrence of germination but no emergence, twisted seedlings, abnormal radicle growth, absence of necrosis and/or rot, presence of crust and/or soil compaction in the seedbed	Mechanical stress such as soil compaction, soil crust formation	Gallardo-Carrera et al. (2007); Lamichhane et al. (2020); Lamichhane and Aubertot (2021)

			Occurrence of germination but no emergence, twisted seedlings, absence of necrosis and/or rot or crusting, presence of clods, crop residues or stones above the seedling in the seedbed	Mechanical stress such as soil clods, crop residues and stones (depending on the type of (no)tillage)	Dürr and Aubertot (2000); Lamichhane et al. (2020)
			Occurrence of germination but no emergence, normal seedlings, absence of necrosis and/or rot or crusting, no clods in the seedbed	Too high sowing depth (technical problem of sowing that leads to a poor soil-seed contact in no-till systems)	Blunk et al. (2021); Kirby (1993); Mahdi et al. (1998)
			Occurrence of germination but no emergence, dried or desiccated seedlings, absence of necrosis and/or rot, no soil crust, neither compaction or large clods in the seedbed.	Post-germination drought stress	Boureima et al. (2011)
Seedling emergence – initial competition among young plants	Seedlings have well-emerged (post-emergence)	Seedling falls down due to the damaged stem at the ground level and remains on the seedbed	Seedling wilting, reddish root necrosis, hypocotyl and seedling collar rot, absence or few secondary roots	Post-emergence damping-off (seed- and soil-borne pathogens)	Rojas et al. (2016); Serrano and Robertson (2018); You et al. (2017)
			Holes and presence of larvae in cotyledons, stem and/or roots; swelling of seedling collar; shrinking and gradual disappearance or entangled seedlings; accumulation of filamentous brown debris	Soil-borne animal pests (e.g. seed maggots, wireworms, symphylans)	Douglas et al. (2017); Furlan et al. (2021b); Vea and Eckenrode (1976)
		Partial or total damage of leaves, damaged stem, uprooted seedlings	Damaged cotyledons and/or part of the hypocotyl/epicotyl at or just after seedling emergence; uprooting of seedlings and their spread in or complete disappearance from the seedbed; pitting and shot-holing; leaf perforation; stunting and poor plant vigour; chewed leaves or	Herbivory related to animal pests (e.g. flea beetles, slugs, birds, rodents, mammals)	Douglas et al. (2017); Douglas and Tooker (2012); Furlan et al. (2021a, 2021b); Lamichhane (2021); Sausse et al. (2021b)

		entire seedlings		
	Seedling falls down and die	Leaf scorching, sudden wilting of the entire plant, pale brown patches in the plot	Frost damage	Brandsæter et al. (2000); Chen et al. (2005); Pescador et al. (2018)
	Seedlings do not fall down on the seedbed	Modification of seedling colors, deformations, abnormal chlorotic or necrotic symptoms but different than those caused by soil-borne pathogens	Problem related to chemical stress (phytotoxicity) or water logging and subsequent root asphyxia	Lamhamdi et al. (2013); Loose et al. (2017); Yasumoto et al. (2011); Zaman et al. (2018)
*An absence of the intact seed could be also related to a rapid seed rotting, especially for small-seeded plant species, under high moisture conditions in the seedbed or when the field diagnosis is performed too late.				

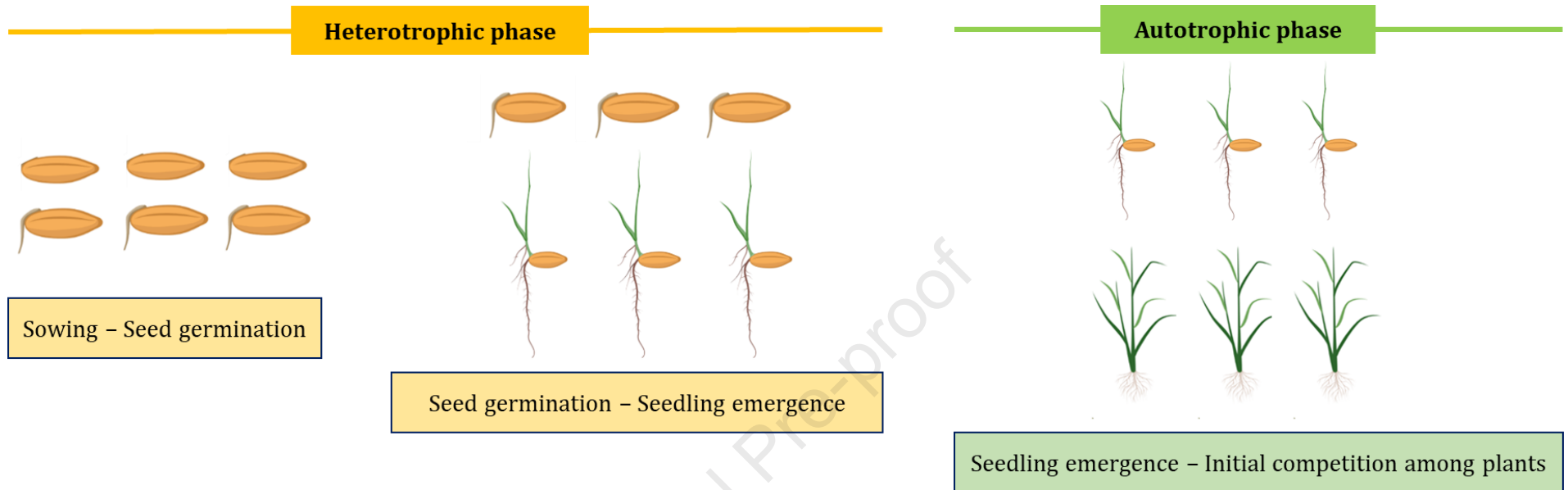


Figure 1. Crop establishment is a phase that consists of three sub-phases viz. sowing to seed germination; seed germination to seedling emergence; and seedling emergence to initial competition among young plants. The former two sub-phases are heterotrophic (i.e. the radicle and seedling development relies on the seed reserves) while the last sub-phase is autotrophic (i.e. the seedling has already developed true leaves that are capable to perform photosynthesis and, thus, do not depend anymore on seed reserves that are already exhausted at this stage).

Figure 2. Poor field emergence of faba bean (a) and brown mustard (b) due to unknown reasons. Identification of the causes leading to non-emergence is a first step to better manage biotic and abiotic factors affecting seed germination and seedling emergence via best cropping practices.



Figure 3. Seed predation due to slugs under directly sown soybean in a relay cropping system. These pests can cause partial (a) or total (b) seed predation when the sowing quality is not optimal (superficial sowing depth, poor soil-seed contact etc.).



Figure 4. Characteristic symptoms of post-emergence seedling damage due to animal pests. Slug feeding (a), and cutting and uprooting by common wood pigeon (b) of soybean seedlings.



Figure 5. Characteristic symptoms of post-emergence seedling damage due to animal pests. Chewed cotyledons or the entire young leaves of soybean by European hare (a), and shot-holing of radish leaves by flea beetle (b).



This is an editorial so there are no highlights.

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Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests:

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