Post-emergence seedling damage due to vertebrate pests and its impact on soybean establishment

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The quality of field crop establishment is an indicator of the productivity and yield quality of a given crop. Several biotic and abiotic factors, as well as cropping practices, affect the quality of field crop establishment. More specifically to soybean, recent studies quantified pre-emergence seedling losses and identified the associated causes of non-emergence. However, little is known about post-emergence seedling damage, mainly due to vertebrate pests, which represent an important problem for growers. A 2-year field observation was conducted to quantify near- and post-emergence seedling damage due to vertebrate pests. The common wood pigeon (*Columba palumbus*) and the European hare (*Lepus europaeus*) were associated with this kind of damage. The characteristic damage due to the common wood pigeon consisted of either partially-damaged cotyledons during emergence or completely uprooted seedlings at emergence. In contrast, damage due to the European hare consisted of chewed seedling or seedling parts. There was significant effect of year ($p < 0.001$) on the final rates of post-emergence seedling damage due to the wood pigeon but not on those due to the European hare. The final rates of post-emergence damage due to the wood pigeon were higher (32% for 2018 and 22% for 2020) compared with those owing to the European hare (18% for 2018 and 17% for 2020). The severity of damage due to vertebrate pests was related to the type of seedling damage that, in turn, affected the capacity of soybean to compensate for post-emergence seedling damage.

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2 **establishment**

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9 **Abstract**

10 The quality of field crop establishment is an indicator of the productivity and yield quality

11 of a given crop. Several biotic and abiotic factors, as well as cropping practices, affect the

12 quality of field crop establishment. More specifically to soybean, recent studies quantified

13 pre-emergence seedling losses and identified the associated causes of non-emergence.

14 However, little is known about post-emergence seedling damage, mainly due to vertebrate

15 pests, which represent an important problem for growers. A 2-year field observation was

16 conducted to quantify near- and post-emergence seedling damage due to vertebrate pests.

17 The common wood pigeon, *Columba palumbus* (Linnaeus), and the European hare, *Lepus*

18 *europaeus* (Pallas), were associated with this kind of damage. The characteristic damage

19 due to the common wood pigeon consisted of either partially-damaged cotyledons during

20 emergence or completely uprooted seedlings at emergence. In contrast, damage due to the

21 European hare consisted of chewed seedling or seedling parts. There was significant effect

22 of year ($p < 0.001$) on the final rates of post-emergence seedling damage due to the wood

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24 damage due to the wood pigeon were higher (32% for 2018 and 22% for 2020) compared

25 with those owing to the European hare (18% for 2018 and 17% for 2020). The severity of

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27 affected the capacity of soybean to compensate for post-emergence seedling damage.

28 **Keywords :** animal damage, bird damage, damage estimates, *Glycine max*

1. Introduction

Soybean (*Glycine max* (L.) Merr.), represents one of the most important leguminous crops worldwide, which is mainly grown for the quality of its protein both for food and feed purposes (Masuda and Goldsmith, 2009). In the European Union (EU), an important decrease in soybean acreage has been observed in the last two decades, leading to several socio-economic and environmental concerns (Labalette et al., 2010). The EU produces only a small fraction of soybean (2.6 Mt that is equivalent to <0.5% of the global production) with over 85% of the grain consumed in the EU being imported from the American continent (FAOSTAT, 2018). More specifically to France, there is a huge gap between the quantity of soybean produced (< 0.5 Mt) and consumed (>5 Mt) annually (FOP, 2018). To fill this gap, public policy in the EU aims at increasing the soybean acreage with three-fold objectives: reducing dependence on genetically-modified soybean imported for feed purpose, satisfying the demand for locally produced non-genetically modified soybean for human consumption, and contributing toward the transition to more sustainable agricultural systems (Berschneider, 2016).

Crop establishment consists of three sub-phases: seed germination, seedling emergence, and early seedling growth (Aubertot et al., 2020). Recent studies conducted in France reported that several biotic and abiotic stresses can affect the quality of soybean establishment (Lamichhane et al., 2020a, 2020b). In particular, mechanical obstacles such as soil aggregates and soil surface crusts have been reported to cause seedling emergence losses while soil-borne pests and pathogens were not a major cause of non-emergence. Nevertheless, these studies did not focus on evaluating post-emergence seedling losses due to biotic stresses in general and those due to vertebrate pests in particular, which were frequently observed across the experimental sites. Post-emergence seedling losses due to vertebrate pests represent an important problem for many field crops, leading to severe economic losses across the globe (Firake et al., 2016; Giunchi et al., 2012; McKee et al., 2020; Nasu and Matsuda, 1976).

58 The objective of this study was to quantify post-emergence seedling damage of soybean

59 due to vertebrate pests at the scale of an experimental site with different spatial

60 replications. This is important to understand whether and to what extent this damage can

61 affect the quality of soybean establishment across the study site. This information may

62 provide important insight for future research that aims to develop and implement cropping

63 practices that limit access to these pests into soybean fields, as well as to design cropping

64 systems that are less vulnerable to vertebrate pest attacks. Collectively, all of this will

65 improve the quality of crop establishment and the competitiveness of the crop in the

66 cropping system.

67 **2. Materials and methods**

68 2.1. Desciption of the study site and experimental design

69 Field observations were carried out for two years (2018 and 2020) in Auzeville

70 experimental station of INRAE (Institut national de recherche pour l'agriculture,

71 l'alimentation et l'environnement; 43.53°N, 1.58°E), southwest of France. The observations

72 were conducted across different field plots of the same study site for the two years. For

73 each year, three field plots grown with the same soybean cultivar (ES Pallador) were

74 chosen to represent spatial replication with regard to the distance from the residential and

75 non-agricultural areas **(Figure 1)**. The latter areas are characterized by the Midi canal with

76 a small strip of bushes, trees and hedgerow that represent a roosting zone for vertebrate

77 pests. Plot location is an important feature as it may affect the type and abundance of

78 vertebrate pests, and associated post-emergence seedling damage (Sausse and Lévy, 2020).

79 Detailed information on the experimental plots are reported in **Table 1**. The size of the

80 experimental plots ranged from 0.50 and 2.40 ha and the sowing date was mid-May as

81 generally practiced by growers in the region. The plots were sown with untreated soybean

82 seeds at 3 cm sowing depth, and 40 seeds m^{-2} planting density with 50 cm inter-row

83 distance, which corresponds to standard practices of farmers in the region (Lamichhane et

84 al., 2020a, 2020b). None of the experimental plots were protected by fences or nylon nets

85 to allow free access to vertebrate pests.

86 The design used for this observational study at the spatial replication scale (i.e. a field plot)

87 is presented in **Figure 2**. Each spatial replication included four microplots (25 x 3 m), and

88 each microplot contained four diagonal rows (each 2 linear meters). The countings were

89 performed on 16 rows/plot that represented replicates.

90   2.2. Field observations and countings

91 The rate of seedling emergence was determined by the ratio between the number of

92 emerged seedlings at VE stage (i.e. when cotyledons are above the soil surface; Fehr and

93 Caviness (1977)) and the sowing density. At each observation, the total number of emerged

94 seedlings with or without damage was counted. For damaged seedlings, the type of damage

95 (i.e. partial-damage of cotyledons, total damage due to uprooting of seedlings, or chewed

96 seedlings or seedling parts) and the associated vertebrate pest(s) were identified by direct

97 preliminary field observations and the literature reports (Firake et al., 2016). Preliminary

98 surveys were based on several years of field observations by technicians who regularly

99 monitored soybean plots every week at the crop establishment phase. This information

100 allowed us to rule out any post-emergence damage due to other types of vertebrates than

101 those reported here. The countings of post-emergence damage were performed when

102 cotyledons were nearly at the VE stage (i. e. when cotyledons begin to pierce the seedbed

103 surface), and continued across the VC (cotyledon stage where unifoliate leaves are unrolled

104 sufficiently so that the leaf edges are not touching) and V1 (first node stage with fully

105 developed leaves are present at unifoliate nodes) growth stages; Fehr and Caviness,

106 (1977)). These stages were chosen as post-emergence damage due to vertebrate pests

107 mainly occur at these phases (Firake et al., 2016). This was further confirmed by

108 preliminary observations during which important seedling losses due to vertebrate pests

109 were observed. The countings of post-emergence seedling losses were made every two

110 days for aproximately two weeks. The countings continued until reaching a plateau with no

111 new damaged seedlings for three consecutive countings.

112

113   2.3. Statistical analyses

114 The rate of seedling emergence was determined by using the following formula:

115
$$Emergence\ (\%) = 100\ X\ \frac{TES}{SD}$$

116   Where TES is the total number of emerged seedlings and SD is the sowing density.

117   The rate of post-emergence damage was calculated using the following formula:

118
$$Post-emergence\ damage\ (\%) = 100\ X\ \frac{TDSdt}{TES}$$

119   Where TDSdt is the number of damaged seedlings per damage type (i.e. partially-damaged

120   cotyledons, uprooted seedlings, or chewed seedlings or seedling parts).

121   The counted number of plants was transformed in percentage, and the data did not meet

122   the normality assumption. Therefore, a non-parametric Kruskall-Wallis test was applied to

123   test for differences between years. The analysis was performed using the R software

124   (Hothorn and Everitt, 2009).

125   **3. Results**

126   3.1.   Soybean emergence rates

127   Final emergence rates of soybean over the two years are presented in **Table 2**. The

128   emergence rates were 82 ± 12 and 72 ± 13 for 2018 and 2020, respectively. There was

129   significant effect of year (p < 0.001) on the final rates of seedling emergence.

130   3.2.   Vertebrate pests and characteristics of post-emergence seedling damage

131   The common wood pigeon, *Columba palumbus* (Linnaeus), and the European hare *Lepus*

132   *europaeus* (Pallas), were two key vertebrate pests regularly observed in our experimental

133   plots. None of these pests caused pre-emergence damage to soybean seedlings. The post-

134   emergence damage caused by these pests could be recognized based on the characteristics

135   of the damage observed in the field.   Seedling damage due to common wood pigeon

136   consisted of either partial damage on the cotyledons as soon as they began to pierce from

137   the seedbed surface **(Figure 3a)** or uprooting of seedlings from the seedbed **(Figure 3b).**

138   No seedling damage due to common wood pigeon was observed after the VC stage. In

139   contrast, seedling damage due to wild hares was observed between the VC and V1 stage,

140   which consisted of chewed seedlings **(Figure 3c, d)**. Unlike common wood pigeon, wild

141   hares did not cause any uprooting of seedlings.

142   3.3.   Severity of post-emergence seedling damage due to vertebrate pests

143   The final rates of post-emergence seedling damage, based on individual characteristics

144   observed in the field, are presented in **Table 3**. There was significant effect of year ($p <$

145   0.001) on the post-emergence seedling damage due to the wood pigeon (i.e. partially-

146   damaged cotyledons and uprooted seedlings). In contrast, no statistically significant

147   differences ($p>0.05$) were found in the post-emergence seedling damage due to the

148   European hare between the two years. Collectively, the final rates of post-emergence

149   seedling damage, due to both vertebrate pests, significantly differed ($p < 0.001$) between

150   the two years. The rates of post-emergence damage were similar over the two years and

151   they ranged from 8 to 12%, 14 to 20%, and 17 to 18% for partially-damaged cotyledons,

152   uprooted seedlings and chewed seedlings, respectively. The final rates of post-emergence

153   damage were 50% and 39% in 2018 and 2020, respectively.

154   3.4.   Recovery ability of damaged seedlings

155   The capacity of damaged seedlings to recover was dependent on the type and intensity of

156   the initial damage caused by vertebrate pests. No seedling growth recovery occurred

157   leading to severe damage and crop emergence failure when cotyledons were entirely

158   damaged during emergence (i.e. when cotyledons still touch the seedbed surface) or

159   completely uprooted by common wood pigeon **(Figure 4)**. In contrast, seedlings recovered

160   their growth by developing new leaves beginning from the nodes, when cotyledons were

161   partially damaged at the near VE stage or when seedlings were partially damaged above

162   the first node at the VE to V1 stage **(Figure 5 a, b)**.

163   **4. Discussion**

164   To the best of the author's knowledge, this is the first study in France and Europe that

165   attempts at quantifying post-emergence damage of soybean due to vertebrate pests via

166   field observations and countings. Previous studies reported crop damage due to vertebrate

167   pests, with millions of dollars of crop losses (Elser et al., 2019; Gebhardt et al., 2011;

168   Swanepoel et al., 2017). However, these losses were mainly related to advanced stages of

169   the crop cycle (i.e. the near harvesting phase) including grain or fruit feeding. In contrast,

170   only little is known on the impact of birds and wild animals on the very early stage of field

171   crops (i.e. seed germination, seedling emergence, and early development stages) that can

172   jeoparadize the quality of field crop establishment. A few studies assessed seed and

173   seedling damage that occurred before the crop establishment phase on corn (Furlan et al.,

174   2017; Khan et al., 2015; Wise, 2018), wheat (Kennedy and Connery, 2008; Khan et al.,

175   2015), oilseed rape (Schillinger and Werner, 2016), speciality crops (Werner et al., 2015),

176   and soybean (Firake et al., 2016).

177   A previous study (Firake et al., 2016) on soybean showed that the rate of seed and seedling

178   damage due to Colombidae is strictly dependent on the crop growth stage. Indeed, the

179   authors highlighted that severe damage occurred at the seed germination, seedling

180   emergence, and green cotyledon stages, followed by only moderate to low damage

181   occurred at the V1 stage, and almost negligeble damage after this stage. Nevertheless, there

182   was no pre-emergence damage due to Colombidae across our study site and that the initial

183   damage commenced to appear nearly at the VC stage, when cotelodons started to pierce the

184   seedbed surface. This difference could be due to many factors including the bird species

185   causing damage, geographical region of the study, the type of landscape, the distance of the

186   experimental site from the residential area, sowing dates, and the type of seedbed

187   preparation. In the study by Firake et al. (2016), the spotted dove, *Spilopelia chinensis*

188   (Scopoli), and occasionally feral pigeon, *Columba livia* (Gmelin), were associated with

189   heavy damage in newly sown soybean fields in northeast India. In contrast, the common

190   wood pigeon and the European hare were associated with post-emergence damage in this

191   study that was carried out in southwestern France and with much earlier sowing dates (i.e.

192   mid-May). This might have affected the bird types involved in seedling damage.

193   In addition to the common wood pigeons, post-emergence seedling damage due to the

194   European hares was observed during this study. A recent research from central India

195   (Bayani et al., 2016) reported damage to soybean and many other crops due to wild

196   mammalian herbivores, including hares, although the damage regarded much advanced

197   stages of the crop. In general, the type of wild mammalian herbivores and their associated

198 damage to crops depend also on the landscape around the field including field-edge habitat
199 and distance from residential area (Sellers et al., 2018).

200 Here, post-emergence seedling damage due to the common wood pigeons was
201 distinguished from that due to the European hares based on the type of damage and crop
202 growth stage. Indeed, the former caused seedling damage at earilier stage than do the latter
203 and the damage type was generally distingushable. Nevertheless, there were a few cases of
204 mixed post-emergence seedling damage caused by both vertebrate pests on the same
205 seedlings (e.g. partially damaged cotyledons recover their growth but they are later
206 attacked by the European hares), which were difficult to distinguish. Future studies are
207 needed to make wider observations of different vertebrate pests on different crop species
208 and the associated seedling damage, which may help precisely estimate seedling damage
209 due to each specific pest cropwise.

210 In this study, the temporal (i.e. year) effect was significant on the post-emergence damage
211 due to the common wood pigeon but not on that due to the European hare. This contrast is
212 interesting and might be due to the capacity of these two pests to move at different scales.
213 For example, the common wood pigeon, as many other birds, is very mobile animal, capable
214 of flying at a large scale within a short period of time. Consequently, the post-emergence
215 damage of a given crop due to birds is determined by three spatial scales (Sausse and Levy,
216 2020): i) the regional scale where they decide to settle for the season (nesting aimed at
217 causing post-emergence damage) that will determine a pool of birds causing post-
218 emergence damage; ii) the landscape scale, where they select the places to feed as part of
219 their daily activity; and iii) the plot scale where they look for food items. In contrast to
220 birds, the movement of the European hare remains limited within a restricted area that
221 may explain the similar level of post-emergence damage occurred between the two years of
222 study. Future studies that take into account a wider spatio-temporal replication of field
223 plots are needed to better understand in this regard.

224 Previous studies reported seed and seedling damages due to Corvidae on many field crops
225 including corn and wheat (Kennedy and Connery, 2008; Khan et al., 2015; Wise, 2018).
226 While Corvidae were occasionally observed across the experimental site, no important

227   damage due to them was found on soybean seed or seedlings. Nevertheless, these birds

228   were more commonly found across neighbouring field plots sown with corn and sunflower.

229   It is possible that Corvidae damage on soybean was negligible because these birds prefer

230   sunflower or corn rather than soybean. However, this study did not investigate the

231   potential correlation between the crop species grown in neighbouring plots and the type

232   and abundance of bird species that needs further exploration.

233   Post-emergence seedling damage due to vertebrate pests can cause severe yield losses.

234   However, the estimation of these losses is extreamly difficult for several reasons. First, the

235   correlation between post-emergence seedling damage due to vertebrate pests and

236   subsequent yield losses are not necessarily linear (Brown et al., 2007). This is especially

237   true for crops that can compensate emergence losses and seedling damage due to their

238   tillering (e.g. wheat) and branching capacity as well as indeterminate or semi-determinate

239   growth (e.g. soybean). In contrast, the correlation between post-emergence seedling

240   damage and subsequent yield losses could be linear for those crops that do not have any

241   compensation ability following early stage damage, such as maize, sugar beet or sunflower.

242   Therefore, as suggested previously (Swanepoel et al., 2017), the impact of any stress and

243   the level of damage at the seedling stage should be viewed as damage and not necessarily

244   as crop losses for the first group of crops. In contrast, this level of damage may correspond

245   to subsequent crop losses for crops without any compensation ability. This means that,

246   seedling damage for the second group of crops can be proposed as a good indicator of crop

247   losses. A previous study reported that for temperate crops, 10% seedling losses resulted in

248   9% crop losses at harvest (Myllymaki, 1989). This study showed that the level of

249   compensation of soybean to seedling damage depends on the seedling growth stage and

250   the type of the damage itself. When cotyledons were completely damaged before the

251   development of first nodes (i.e. before the V1 stage), seedlings most often were unable to

252   recover. In contrast, when seedlings were partially damaged at the V1 stage and above the

253   first node, they could develop new leaves beginning from the first nodes which, however,

254   led to a very heterogeneous growth stage of the crop.

255   **5. Conclusions**

256   The present study provides a first estimation of seedling damage due to the common wood

257   pigeon and the European hare that are key vertebrate pests affecting nearly emerged and

258   emerged soybean seedlings in southwestern France. Although the rates of soybean seedling

259   damage due to vertebrate pests were relatively high, most often, the crop was able to

260   partially compensate this damage through its branching capacity and semi-determinate or

261   indeterminate growth habit. However, in some cases, post-emergence damage may directly

262   affect soybean yield especially when cotyledons are entirely damaged during emergence

263   (i.e. when cotyledons still touch the seedbed surface) or completely uprooted by birds.

264   The results presented in this study were based on 2-year field observations at a small-scale

265   spatial replication. The lack of a large-scale spatial replication and the number of crop

266   genotype (only one) considered represent a limit of this study. The heterogeneous size of

267   the plots used as spatial replication consititutes another drawback of this study. Indeed, the

268   size of a plot determines the available edge habitat that, in turn, may affect the extent and

269   type of post-emergence damage. Future studies that take into account different study sites

270   and crop genotypes, heterogeneous landscape composition, and sowing dates are needed

271   to provide insights into potential correlations between the quality of soybean

272   establishment and grain yield, both in terms of quality and quanity. Finally, the database

273   generated by this study can be used to feed a qualitative model called CESIM (Crop

274   Establishment SIMulator; Lamichhane et al., 2020c). This model, in addition to emergence

275   losses due to abiotic and biotic factors, and cropping practices, also takes into account the

276   impact of post-emergence seedling damage on the quality of field crop establishment.

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281

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Key description of the field plots used for the observational study

3   **Table 1.** Key description of the field plots used for the observational study

Year	Replicated plots	Plot size (ha)	Distance from the Midi canal (km)[1]	Distance from the residential area (km)	Soil texture (proportion of clay : silt : sand in %)
2018	Evapo	1.09	0.10	0.45	24 : 24 : 52
	Micmac	0.98	0.08	0.10	28 : 35 : 37
	Cantine	0.95	0.66	0.02	25 : 38 : 37
2020	TE	2.40	0.01	0.55	37 : 38 : 25
	Micmac	0.98	0.08	0.10	31 : 38 : 31
	Micro-Est	0.50	0.48	0.02	28 : 30 : 42

[1]A small strip, composed of bushes, trees and hedgerow up to 30 m high, separates the field plots from the Midi canal that represent a roosting area for vertebrate pests; green highlight: plots that were closer to the canal and farther from the residential area; yellow highlight: plots that were closer to the residential area and farther from the Midi canal

Average final emergence rate (± standard deviation) of soybean (cv. ES Pallador) in relation to spatio-temporal replication of field plots

3 **Table 2.** Average final emergence rate (± standard deviation) of soybean (cv. ES Pallador) in relation to spatio-temporal
4 replication of field plots

Year	Plot	Emergence (% ± SD)
2018	Evapo	
	Micmac	$82^b \pm 12$
	Cantine	
2020	TE	
	Micmac	$72^a \pm 13$
	Micro-Est	

Means followed by the different letter are significantly different at $p < 0.05$

Post emergence damage (± standard deviation) caused by the common wood pigeon and the European hare on soybean

1 **Table 3.** Post emergence damage (± standard deviation) caused by the common wood pigeon and the European hare on
2 soybean

Year	Partially-damaged cotyledons (%)	Uprooted seedlings (%)	Chewed plantlets (%)	Total damage (%)
2018	12 ± 4	20 ± 9	18 ± 14	50 ± 15
2020	8 ± 3	14 ± 7	17 ± 10	39 ± 16
p	***	***	NS	***

NS: not significant; *** $p < 0.001$

Figure 1

An aerial view of the experimental site. The areas delimited in red and yellow represent the location of the field plots entirely sown with soybean, in 2018 and 2020, respectively. The information reported next to the delimited areas represent the histori

Figure 2

Study design used for the observational study at the scale of spatial replication (i.e. plot level) for countings of post-emergence seedling damage due to vertebrate pests. Following band sowing, each field plot was divided into four micro plots (M1 to M4
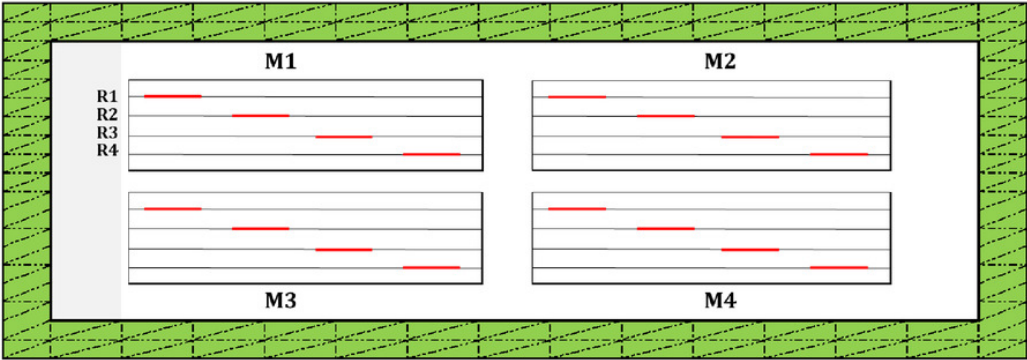
Figure 3

Characteristic post-emergence seedling damages caused by the common wood pigeon (a, b) and the European hare (c, d) on soybean. The cotyledons can be partially damaged by birds during the emergence phase (a) or the entire seedling can be uprooted and scat

Figure 4

Post-emergence seedling damage due to the common wood pigeon can lead to total crop establishment failure with severe direct (re-sowing costs, yield losses) and indirect (increased weed pressure during the cropping season with increased weed seedbank for

Figure 5

Heterogeneous growth stage of soybean seedlings due to post-emergence seedling damage by vertebrate pests. Damaged seedlings partly compensate their growth that mainly depends on the pest type and growth stage during which the damage occurred.