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Can repellent crops reduce the abundance of the common vole (*Microtus arvalis*) as a way to reduce crop damage?

Josef Suchomel[a,] * suchomel@mendelu.cz, Jan Šipoš[a] sipos@mendelu.cz, Marta Heroldová[b] heroldmarta@seznam.cz

[a]Department of Zoology, Fisheries, Hydrobiology and Apiculture, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00, Brno, Czech Republic,

[b]Department of Forest Ecology, Faculty of Forestry and Wood Technology, Mendel University in Brno, Zemědělská 3, 613 00, Brno, Czech Republic

*Corresponding author

Abstract

The common vole is one of the most damaging rodents in agriculture. A number of methods are used to suppress its numbers and limit damage. One option is growing crops that are not suitable for voles; this might limit their numbers and distribution. Through long-term monitoring of common voles throughout the Czech Republic, their abundance in eleven crop types (annual, biennial and perennial crops) was evaluated through active burrow counts. Reference crops were selected from perennials and biennials and annual crops were selected as potential repellents. The perennial crops were clover with alfalfa, which serve as the primary habitat for voles. These crops are where voles are found in their highest densities, and from which they spread to the surrounding crops during periods of high abundance. The biennial winter rape was selected because it provides favourable conditions for voles to overwinter and multiply rapidly in the spring. Compared to perennial crops and winter rape, significantly lower numbers of voles were found in onions, poppy seeds and maize. Additionally, fewer voles were also found in mustard compared to perennial crops. Onion and poppy were the only crops to show a significantly lower abundance of voles in comparison to wheat. The annual crops tested are unattractive to voles and due to the cultivation practices used, they do not even have enough weeds as food. As profitable crops they can be cultivated over sufficiently large areas to potentially prevent the spread of voles to surrounding crops, especially during outbreak years.

Key words: common vole, annual crops, crop damage, onion, habitat

1. Introduction

In Central European countries, the common vole (*Microtus arvalis*, Pallas 1787) is one of the dominant pest species in agroecosystems (Jacob and Tkadlec, 2010; Jacob, 2014). Its preference for crops depends on the frequency of disturbances, particularly ploughing. Permanent stands (e.g. grasslands, pastures, etc.) and perennial crops (e.g. alfalfa, clover) provide the most favourable conditions (Jánová and Heroldová, 2016; Rodríguez-Pastor et al., 2016; Santamaria et al., 2019). Among those, alfalfa (*Medicago sativa*) and clover (*Trifolium* spp.) are the most commonly used (Tertil, 1977; Babinska-Werka, 1979; Batzli, 1985; Balmelli et al., 1999; Lantová and Lanta, 2008; Jánová et al., 2016). Winter crops, represented by cereal species and winter rape (*Brassica napus*), provide food and shelter, aiding in the successful overwintering of voles (Heroldová et al. 2021a, b). It is expected that the highest damages and losses would occur in such preferred crops (Suchomel et al., 2021).

There is an irregular variation in the degree of damage suffered by agricultural crops due to cyclic changes in vole population dynamics that takes place every 2–5 years (Jacob et al., 2014). However, in recent years, climate change has had an effect and vole outbreaks have been more intense and may affect large areas of Europe (Jacob et al., 2020). Therefore, efforts are underway to optimize the existing methods of vole population management and damage reduction, as well as to explore new methods to regulate vole numbers (Tobin and Fall, 2004; Aulický et al., 2022).

There are numerous methods available to allow the management of vole populations, each of which has its own distinct effects. The most common and effective method is chemical control using rodenticides, current practices predominantly rely on zinc phosphide (Jacob et al., 2014; Aulický et al., 2022). At present, however, their use in the European Union is significantly limited. There is an effort to replace them with integrated pest management or ecologically-based rodent management programs (Tobin and Fall, 2004; Singleton et al., 2007). Agrotechnical interventions during plant cultivation are important components of an integrated ecological protection methodology. These interventions include the removal of vegetation (by mowing meadows and harvesting crops), as well as practices such as mulching, stubble-tillage, and ploughing (Jacob et al., 2014). However, with the exception of ploughing, most of these interventions do not have a sufficiently large effect (Jacob, 2003). Attention is also focused on biological regulation, which involves the use of predators or pathogens (Jacob et al., 2014; Labuschagne et al., 2016; Williams et al., 2018), as well as methods to limit vole fertility (Chambers et al., 1999; Jacob et al., 2004). Plant repellents, based on secondary plant metabolites, are being tested for their effectiveness in repelling rodents (Hansen et al., 2016a, b; Jokić et al., 2018; Quasim et al., 2023). However, all these methods have limitations and are only partially effective.

The effort to attempt to implement an integrated system incorporating ecological processes is also tied to a shift in the perception of the role of the common vole in agrocenoses, where voles provide a wide range of ecosystem services (Martin, 2003). This approach focuses on minimizing vole populations to below the damage threshold rather than the pursuit of their total elimination. One approach is through long-term preventative measures related to the structure of the landscape and the reinforcement of self-regulatory mechanisms, including the utilization of ecosystem services from predators, among others (Lindell et al., 2018; Williams et al., 2018).

The creation of unsuitable habitats, that restrict the occurrence and distribution of voles, can be an effective strategy that allows the optimisation of vole populations and this minimizes crop damage. Various different crops can be used within the sowing plan to create habitats that are unsuitable for voles. Such crops create conditions unsuitable for voles through their biological properties and agricultural cultivation techniques. Mainly annual crops, voles find these plants unattractive and they are intensively cultivated to control weeds. Examples include ornamental flowering bulbs (Curtis et al., 2009), as well as selected bulbs used in cooking and cereals (Nosek, 1956; Holišová, 1959). Many of those crops are commonly cultivated and have economic value. Therefore, in practice they can be utilized as potential barriers against the spread of voles from their primary habitats to other crops.

Through the long-term monitoring of the occurrence of the common vole in various crops across the Czech Republic, we assessed its abundance in annual, biannual and perennial crops, and identified species that have the potential to be a repellent for the common vole. This approach, using the evaluated crops, could contribute to a limitation to plant damage and thus yields in ordinary agricultural practice. We assume that certain agricultural crops (such as the poppy (*Papaver somniferum*), white mustard (*Sinapis alba*), maize (*Zea mays*), caraway (*Carum carvi*), purple tansy (*Phacelia tanacetifolia*) and pea (*Pisum sativum*)) can act as repellents and prevent the spread of voles to economically important crops. Therefore, our hypothesis is that there are significantly fewer active burrows in these crops in comparison to the number found in economically important crops (such as winter wheat (*Triticum aestivum*) and winter rape) and perennial crops (such as alfalfa and clover).

2. Material and methods

2.1. Data collection

The data on the presence of common voles in crops were provided by the Division of Plant Health of the Czech Republic, based on a count of active burrow entrances. Active burrows are those visibly used by voles, indicated by signs such as fresh food and faeces at the entrance, and evidence of vegetation consumption around the burrow. Four transects were laid out within each field (Zapletal et al., 2001). The number of active burrows on four plots (1000 m^2) was multiplied by 10 to calculate the burrow index per hectare (BI/ha).

This study utilized data from a large database spanning the years 2000 to 2018 (Table 1), collected from 76 districts across the Czech Republic. We evaluated data from a total of 19,873 data records, covering BI/ha in the spring (February to May) and autumn (October to December). Detailed methodology, current situation, and maps are available on the website: http://eagri.cz/public/app/srs_pub/fytoportal/fy-public/, though the information is in Czech. The applicability of this methodology has been demonstrated by Lisická et al. (2007) and Tkadlec et al. (2011).

2.2. Crops under study

The analysis focused on the abundance of common voles (active BI) in crops that vary in their degree of attractiveness to voles within the agricultural landscape of Central Europe. Such crops were annuals, biennials and perennials (Table 1). From those, three reference crops were selected to serve as comparative benchmarks. These included leguminous crops (alfalfa, clover), which are occupied year-round by the common vole and show the highest population densities. The second reference crop chosen was winter rape, which provides a highly suitable habitat for voles to overwinter and exhibit robust spring reproduction. The final reference crop chosen was winter wheat, recognized as one of our most important agricultural crops. The number of years of data available for these crops differed and correlated with the intensity of monitoring. The monitoring effort of the state administration was noticeably lower for annual crops (excluding wheat and barley *Hordeum vulgare*) compared to higher risk biennials, such as rape, and perennials. Crops monitored for more than three years were selected for objective evaluation.

The monitoring of each crop was conducted across the Czech Republic (Supplementary data, Appendix S1 and S2). The Supplementary data show that for the majority of crop types (i.e. perennial crops, winter rape, winter wheat) more than 100 fields were sampled each year. The other crop types analysed were not monitored as a priority because they are not important to predict vole outbreaks. Therefore, we have a significantly smaller number of sampled fields for these crops compared to the main economic crops.

2.3. Data analysis

The importance of crops to predict vole occurrence was modelled using a Bayesian generalized linear model (BRM) implemented in the 'brms' package from the R statistical program (Bürkner, 2021). In the BRM model, crop type was used as the fixed-effect variable, while the variables district (NUTS 3) and sampling season nested within year were used as crossed random intercept factors. To test whether repellent plants are less colonized by voles during outbreak years (represented by 2000, 2005, 2010, 2012, 2015, and 2018), we created a second model. This model differed from the first by including an explanatory variable that accounted for the interaction between crop type and the year of the vole outbreak. As the dependent variable, the decadic logarithm of the number of active burrows per hectare was used. Noninformative priors were set as the prior distribution to model uncertainty in the model parameters, and Gaussian was chosen as the response distribution. To achieve convergence and good mixing across multiple chains, we set up 4 chains in the model with 4,000 iterations each using a Markov Chain Monte Carlo (MCMC). The robustness of the MCMC simulation in ensuring convergence was assessed using a R-hat statistic, which was below the threshold of

1.2, indicating good model convergence. Bayesian highest density credible intervals and Bayesian 95% prediction intervals of the estimates were obtained using the 'mcmc_intervals' function of the 'bayesplot' package (Gabri and Mahr, 2022).

3. Results

A total of 11 crop types were evaluated (Fig. 1). One of the results of the Bayesian data analysis revealed a non-significant effect of outbreak years and their interactions with crop types, with the exception of purple tansy, which was more heavily occupied during vole outbreak years compared to years with normal vole populations (Appendix S3). In a separate Bayesian model comparing the effect of different crop types with the reference crops (i.e., perennial fodders, winter rape, and winter wheat), we found a clear reduction in the number of active burrows in repellent plants (Fig. 2-4). When compared to perennial fodders (Fig. 2), the lowest number of active burrows was found in onions (*Allium cepa*) (Bayesian statistics CI: l-95% = -2.886, u-95% = -1.241), followed by maize (Bayesian statistics CI: l-95% = -1.565, u-95% = -0.523), poppy (Bayesian statistics CI: l-95% = -1.462, u-95% = -0.749) and mustard (Bayesian statistics CI: l-95% = -0.827, u-95% = -0.245). Significantly lower number of active burrows were also observed in winter crops (winter wheat – Bayesian statistics CI: l-95% = -0.774, u-95% = -0.702 and winter rape – Bayesian statistics CI: l-95% = -0.536, u-95% = -0.466) (Fig. 2).

Compared to winter rape (Fig. 3), onions showed a significantly lower number of voles (Bayesian statistics CI: l-95% = -2.374, u-95% = -0.785), followed by poppies (Bayesian statistics CI: l-95% = -0.950, u-95% = - 0.247), maize (Bayesian statistics CI: l-95% = -1.065, u-95% = - 0.002) and winter wheat (Bayesian statistics CI: l-95% = -0.263, u-95% = -0.213). Conversely, significantly higher numbers, compared to rape, were found in the perennial fodders (Bayesian statistics CI: l-95% = 0.465, u-95% = 0.536), caraway (Bayesian statistics

CI: l-95% = 0.133, u-95% = 0.547), and fallow areas (Bayesian statistics CI: l-95% = 0.452, u-95% = 1.283). The differences compared to other crops were not statistically significant.

When compared to winter wheat, a statistically significantly lower number of voles were only found in onions (Bayesian statistics CI: l-95% = -2.110, CI u-95% = -0.563) and poppies (Bayesian statistics CI: l-95% = -0.714, CI u-95% = -0.022). The abundance of voles in maize crops was not significantly different. The other crops under test had a significantly higher abundance of voles (Fig. 4).

4. Discussion

The results demonstrate that the selected annual crops host significantly fewer voles over the long term in comparison to primary perennial habitats such as perennial fodders and ruderal plants, and even in comparison to biennial crops such as rape and wheat. Onion crops were found to be the least suitable habitat. This could be attributed to the presence of specific secondary metabolites that repel rodents. This phenomenon has been demonstrated in laboratory experiments, for example, on water voles *Arvicola amphibius* (Fisher et al., 2013). Garlic (*Allium sativum*) also repels voles, indicating a similar effect to that observed with onions (Fisher et al., 2013). It can be assumed that most plants from the Amaryllidaceae family, including representatives of the *Allium* genus have properties that repel voles. Food analyses have confirmed that these plant species are not consumed by the common vole (Nosek, 1956; Holišová, 1959). The cultivation technology used for onions, particularly the intensive weed suppression using agricultural techniques and chemical regulation also leads to an environment unsuitable for voles (Rubin, 1990; Dhananivetha et al., 2017). Both factors lead to a lack of food in the form of weeds and to limited vegetation cover, leaving the voles vulnerable to predation.

Due to the agricultural cultivation techniques used and the absence of food in the form of weeds, voles only minimally colonize maize. Intensive cultivation practices suppress weeds and disturbs the top layer of the soil. The growth of weeds is further limited by herbicides and the presence of the maize during the growing season (Glowacka, 2011; Page et al., 2012). Other cultivated cereals (Poaceae), such as sorghum (*Sorghum* spp.) can have a role as equally unsuitable habitats. Sorghum (*Sorghum bicolor*), is similar to maize in terms of its growth and management, but unlike maize it also acts as a repellent. Sorghum contains cyanide and can be toxic to herbivorous mammals (Giantin et al., 2024). The vole will only eat the grains of sorghum and maize, not the green parts of the plants (Holišová, 1959) and is only able to reach the grains when the plants are on the ground, typically due to weather or the activities of other animals, such as wild boar (Tóth et al., 2023). Tillage and intensive weed control can ensure that within such crops the habitat continues to be unsuitable for voles, especially during the early stages of growth when they are particularly susceptible (Vencill and Banks, 1994). If those crops are grown in a no-tillage system, they may be more attractive to voles, as they tend to survive better in such systems (Heroldová et al., 2018). Common vole populations in sorghum stands have not yet been studied, but preliminary results indicate there are low numbers, similar to those observed in maize (Tóth et al., 2023).

Poppy and mustard are also not a preferred food for the common vole, as voles often ignore them (Holišová, 1959; Balmelli et al., 1999). Poppy stands may contain a variety of species of weeds, but they are highest in number at the margins of the fields and significantly decrease towards the centre, thereby limiting the potential food supply for voles (Pinke et al., 2011). Mustard stands suppress the formation of weed communities, especially during the summer, which means a lack of food for voles (Alcántara et al., 2011).

All these crops are secondary habitats that voles only typically inhabit during population outbreaks (Stein, 1958; Pelikán, 1959). Even during outbreak years, the abundance of voles in these habitats remains low, as indicated by the findings of this study (Appendix S3). Hence, it can be assumed that such crops are able to limit the spread of voles to other crops if the planted area is large enough. To be effective as a barrier, they should be grown in strips with a width of more than 20 meters. This width corresponds to the maximum movement distance of the common vole. Depending on the type of crop and seasonal development of vegetation, voles usually only move 0.5–9 m from the burrow, with a maximum range of up to 19 meters. By autumn, the burrows can reach a maximum length of 20 meters (Stein, 1958; Pelikán, 1959; Zejda et. al, 2002). Natal and breeding females (dispersers) can spread further to establish a new nest, at distances ranging from 16 to 537 meters (Boyce and Boyce, 1988). In areas with sparser vegetation, voles move a shorter distance from the burrow (approx. 0.5 meters), while long-distance movement (tens of meters) only occurs in dense and closed vegetation (Pelikán, 1959; Zejda et al., 2002). Wide-row crops with low plant density and intensive cultivation thus hinder vole movement, which typically occurs only over short distances (in the order of meters). Crops colonized by voles that have come from strips of permanent vegetation or stands of perennial forage are most densely populated near the edges (Rodríguez-Pastor et al., 2016). The vole population density decreases towards the centre of the field (Rodríguez-Pastor et al., 2016; Suchomel et al., 2021), as those crops are unsuitable for voles, essentially acting as 'sink sites'. Therefore, an increase in the width of the strip of the selected repellent crop can be expected to enhance their effectiveness.

The effect of plant stands that repel rodents has only occasionally been tested. For example, there have been studies on ornamental plants and within orchards (Curtis et al., 2003; Wiman et al., 2009), but research in fields is lacking. A demonstrable influence was observed, for example, with the sweet woodruff (*Galium odoratum*), which, however is not an economically beneficial crop for farmers. On the other hand, the tested plants do fulfil the need to provide an economic benefit in addition to the need to reduce vole numbers. The demonstrably lower abundance of voles in onion, corn and poppy stands suggests that they can serve as barriers, not only against the spread of voles from primary habitats such as perennial forage and permanent stands, but also against the spread from winter rape to cereals. Growing winter rape in the vicinity of cereals poses a risk. It facilitates the survival of the common vole over the winter and provides the necessary conditions for reproduction in the spring (Heroldová et al., 2021b). However, at the end of its phenological development, during ripening in June, winter rape becomes completely unsuitable as a habitat for voles due to a lack of food which causes the voles to leave. If other suitable crops, such as cereals, are grown next to winter rape, voles will quickly colonize them and cause considerable damage. This is particularly evident during rodent outbreak years (Suchomel et al., 2021). Restrictive belts of selected annual crops can prevent or significantly reduce this damage.

One of the prospective crops recently introduced into our range of cultivated plants is the sunflower (*Helianthus annuus*). According to Jánová et al. (2011), two years of snap-trapping of rodent species in various crops in years with high common vole populations resulted in the capture of zero common voles in 17 sunflower fields. There was also a very low number of burrows found at the margins of the fields. The same experiment was also carried out within 20 maize fields with similar results (Jánová et al. 2011). The low number of common voles in both of these crops in all phenological stages (even if young leaves of crops were within the reach of the voles) might find a practical application in plant agriculture management. Thereby such crops may be used as an isolating zone that protect more attractive crops against vole colonisation.

5. Conclusion

The results clearly demonstrate that the selected types of annual crop host significantly lower numbers of voles than perennial crops. In the case of wide-row crops with intensive cultivation and weed suppression, the method of cultivation significantly limits the food supply for voles (weeds) and the vegetation cover needed by voles to hide from predators. Additionally, as a food source the tested crops are not attractive to voles, likely due to secondary metabolites or the low quality of the plant biomass. Overall, they provide an unsuitable habitat for the common vole. When combined with their economic or other benefits for farmers, such crops can be grown in large enough areas to serve as potential barriers against the spread of voles to the main economic crops such as cereals, rape, sugar beet, etc. In theory, we might generalise and expect that these properties will apply to all crops of this type. It is important to apply the cultivation technology for broad-row crops in a way that ensures a poor quality habitat for voles, achieved through practices such as weed minimization and soil disturbance, i.e., tilling. In the case of no-tillage cultivation, where the quality of the habitat is higher for voles, there is a risk that they will successfully settle. As a future research project, it would be appropriate to test these and other similar types of crops in a controlled experiment. The aims would be: 1) to determine the optimum width of a stand in terms of its effectiveness in limiting the spread of voles (with a hypothesis of more than 20 m); 2) to investigate the possibility of the effectiveness of some types of crops in a no-till cultivation system.

CRediT authorship contribution statement

Josef Suchomel: Conceptualization, Data curation, Methodology, Writing – original draft, Writing – review & editing. **Jan Šipoš:** Data curation, Methodology, Formal analysis, Writing – review & editing. **Marta Heroldová:** Conceptualization, Methodology, Writing – review & editing.

Declaration of competing interest

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.

Data availability

Data will be made available on request.

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References

Alcántara, C., Pujadas, A., Saavedra, M., 2011. Management of *Sinapis alba* subsp. *mairei* winter cover crop residues for summer weed control in southern Spain. Crop Prot. 30, 1239–1244. https://doi.org/10.1016/j.cropro.2011.04.007.

Aulický, R., Tkadlec, E., Suchomel, J., Fraňková, M., Heroldová, M., Stejskal, V., 2022. Historical and current perspectives of monitoring and management of the common vole in Czech lands. Agronomy 12 (7), 1629. https://www.mdpi.com/2073-4395/12/7/1629.

Babinska-Werka, J., 1979. Effects of common vole on alfalfa crop. Acta Theriol. 24, 281–297.

Balmelli, L., Nentwig, W., Airoldi J.P., 1999. Food preferences of the common vole *Microtus arvalis* in the agricultural landscape with regard to nutritional components of plants. Int. J. Mammal. Biol. 64 (3), 154–168.

Batzli, G.O., 1985. The role of nutrition in population cycles of rodents. Acta Zool. Fenn. 173, 13–17.

Boyce, C.C.K., Boyce, J.L., 1988. Population biology of *Microtus arvalis*. II. Natal and breeding dispersal of females. J. Anim. Ecol. 57, 723–736.

Burkner, P.C., 2017. brms: An r package for Bayesian multilevel models using Stan. Journal of statistical software 80, 1–28. 10.18637/jss.v080.i01.

Chambers, L.K., Singleton, G.R., Hinds, L.A., 1999. Fertility control of wild mouse populations: the effects of hormonal competence and an imposed level of sterility. Wildl. Res. 26 (5), 579–591.

Curtis, P.D., Rowland, E.D., Harribal, M.M., Curtis, G.B., Renwick, J.A., Martin-Rehrmann, M.D., Good G.L., 2003. Plant compounds in *Pachysandra terminalis* that act as feeding deterrents to prairie meadow voles. Hort. Science 38, 390–394.

Curtis, P.D., Curtis, G.B., Miller, W.B., 2009. Relative Resistance of Ornamental Flowering Bulbs to Feeding Damage by Voles. Hort. Technology, 19 (3), 499–503.

Dhananivetha, M., Amnullah, M.M., Arthanari Murali, P., Mariappan, S., 2017. Weed management in onion: A review. Agricultural Review, 38 (1), 76–80. doi: 10.18805/ag.v0iOF.7311.

Fischer, D., Imholt, C., Pelz, H.J., Wink, M., Prokop, A., Jacob, J., 2013. The repelling effect of plant secondary metabolites on water voles, *Arvicola amphibius*. Pest Manag. Sci. 69, 437–443. https://doi.org/10.1002/ps.3438.

Gabry, J., Mahr, T., 2022. "bayesplot: Plotting for Bayesian Models." R package version 1.10.0.

Giantin, S., Franzin, A., Brusa, F., Montemurro, V., Bozzetta, E., Caprai, E., Fedrizzi, G., Girolami, F., Nebbia, C., 2024. Overview of Cyanide Poisoning in Cattle from *Sorghum halepense* and *S. bicolor* Cultivars in Northwest Italy. Animals 14, 743. https://doi.org/10.3390/ani14050743.

Glowacka, A., 2011. Dominant weeds in maize (*Zea mays* L.) cultivation and their competitiveness under conditions of various methods of weed control. Acta Agrobotanica 64 (2), 119–126. https://doi.org/10.5586/aa.2011.023.

Hansen, S.C., Stolter, C., Imholt, C., Jacob, J., 2016a. Plant Secondary Metabolites as Rodent Repellents: a Systematic Review. J. Chem. Ecol. 42, 970–983. https://doi.org/10.1007/s10886-016-0760-5.

Hansen, S.C., Stolter, C., Jacob, J., 2016b. Effect of plant secondary metabolites on feeding behavior of microtine and arvicoline rodent species. J. Pest Sci. 84 (4), 955–963. https://doi.org/10.1007/s10340-015-0723-6.

Heroldová, M., Jánová, E., Bryja, J., Tkadlec, E., 2005. Set-aside plots – source of small mammal pests? Folia Zool. 54, 337–350.

Heroldová, M., Michalko, R., Suchomel, J., Zejda, J., 2018. Influence of no-tillage versus tillage system on common vole (*Microtus arvalis*) population density. Pest Manag. Sci. 74, 1346–1350. https://doi.org/10.1002/ps.4809.

Heroldová, M., Šipoš, J., Suchomel, J., Zejda J., 2021a. Influence of crop type on the common vole abundance in Central European agroecosystems. Agric. Ecosyst. Environ. 315, 107443. https://doi.org/10.1016/j.agee.2021.107443.

Heroldová, M., Šipoš, J., Suchomel, J., Zejda, J., 2021b. Interactions between common vole and winter rape. Pest Manag. Sci. 77, 599–603. https://doi.org/10.1002/ps.6050.

Holišová, V., 1959. Potrava hraboše polního, in: Kratochvíl, J. (Ed.), Hraboš polní *(Microtus arvalis)*. NČAV, Praha, pp. 100–129.

Jacob, J., Herawati, N.A., Davis, S.A., Singleton, G.R., 2004. The impact of sterilised females on enclosed populations of ricefield rats. J. Wildl. Manag. 68 (4), 1130–1137.

Jacob, J., Imholt, C., Caminero-Saldaña, C., Couval, G., Giraudoux, P., Herrero-Cófreces, S., Horváth, G., Luque-Larena, J.J., Tkadlec, E., Wymenga, E., 2020. Europe-wide outbreaks of common voles in 2019. J. Pest Sci. 93, 703–709. https://doi.org/10.1007/s10340-020-01200-2.

Jacob, J., Manson, P., Barfknecht, R., Fredricks, T., 2014. Common vole (*Microtus arvalis*) ecology and management: implications for risk assessment of plant protection products. Pest Manage. Sci. 70, 869-878. https://doi.org/10.1002/ps.3695.

Jacob, J., Tkadlec, E., 2010. Rodent outbreaks in Europe: dynamics and damage, in: Singleton, G.R., Belmain, S.R., Brown, P.R., Hardy, B. (Eds), Rodent outbreaks – ecology and impacts. Int. Rice Res. Ins., Los Baños, pp. 207–223.

Jacob, J., 2003. Short-term effects of farming practices on populations of common voles. Agric. Ecosyst. Environ. 95 (1), 321–325. https://doi.org/10.1016/S0167-8809(02)00084-1.

Jánová, E., Heroldová, M., 2016. Response of small mammals to variable agriculture landscape in Central Europe. Mamm. Biol. 81, 488–493. https://doi.org/10.1016/j.mambio.2016.06.004.

Jánová, E., Heroldová, M., Čepelka, L., 2016. The rodent quality of the diet and its relation to crops and other environment and population parameters in agriculture landscape. Sci. Total Environ. 562, 164–169. https://doi.org/10.1016/j. scitotenv.2016.03.165.

Jánová, E., Heroldová, M., Konečný, A., Bryja, J., 2011. Traditional and diversified crops in South Moravia (Czech Republic): habitat preferences of common vole and mice species. Mamm. Biol. 76, 570–576. https://doi.org/10.1016/j.mambio.2011.04.003.

Jokić, G., Tanja, A., Marković, T., Đedovi, S., Brki, D., Sa, M., 2018. Wild *Mus musculus* response on two different essential oils with high repellent potential. J. Stored Prod. Res. 79, 106–111. https://doi.org/10.1016/j.jspr.2018.10.001.

Labuschagne, L., Swanepoel, L.H., Taylor, P.J., Belmain, S.R., Keith, M., 2016. Are avian predators effective biological control agents for rodent pest management in agricultural systems? Biol. Control 101, 94–102. http://dx.doi.org/10.1016/j.biocontrol.2016.07.003.

Lantová, P., Lanta, V., 2008. Food selection in *Microtus arvalis*: the role of plant functional traits. Ecol. Res. 24, 831–838. https://doi.org/10.1007/s11284-008- 0556-3.

Lindell, C., Eaton, R.A., Howard, P.H., Roels, S.M., Shave, M.E., 2018. Enhancing agricultural landscapes to increase crop pest reduction by vertebrates. Agric. Ecosyst. Environ. 257, 1–11. https://doi.org/10.1016/j.agee.2018.01.028.

Lisická, L., Losík, J., Zejda, J., Heroldová, M., Nesvadbová, J., Tkadlec, E., 2007. Measurement error in burrow index to monitor relative population size in the common vole. Folia Zool. 56, 169–176.

Martin, G., 2003. The role of small ground-foraging mammals in topsoil health and biodiversity: implications to management and restoration. Ecol. Manag. Restor. 4 (2), 114–119. https://doi.org/10.1046/j.1442-8903.2003.00145.x.

Nosek, J., 1956. Příspěvek k potravě hraboše polního (*Microtus arvalis* Pall.) se zřetelem ke škodám v zahradnictví. Biológia 11 (6), Bratislava.

Page, E.R., Cerrudo, D., Westra, P., Loux, M., Smith, K., Foresman, C., Wright, H., Swanton, C.J., 2012. Why Early Season Weed Control Is Important in Maize. Weed Sci. 60 (3), 423–430. https://doi.org/10.1614/WS-D-11-00183.1.

Pelikán, J., 1959. Bionomie hraboše polního, in: Kratochvíl, J. (Ed.), Hraboš polní *(Microtus arvalis)*. NČAV, Praha, pp. 80–99.

Pinke, G., Pál, R.W., Tóth, K., Karácsony, P., Czúcz, B., Botta-Dukát, Z., 2011. Weed vegetation of poppy (*Papaver somniferum*) fields in Hungary: effects of management and environmental factors on species composition. Weed Res. 51, 621–630. https://doi.org/10.1111/j.1365-3180.2011.00885.x.

Rodríguez-Pastor, R., Luque-Larena, J.J., Lambin, X., Mougeot, F., 2016. "Living on the edge": the role of field margins for common vole (*Microtus arvalis*) populations in recently colonised Mediterranean farmland. Agric. Ecosyst. Environ. 231, 206–217. https://doi.org/10.1016/j.agee.2016.06.041.

Rubin, B., 1990. Weed Competition and Weed Control in Allium Crops, in: Rabinowitch, H.D. (Ed.): Onions and Allied Crops. Volume II: Agronomy Biotic Interactions. CRC Press, Boca Raton, pp. 61–83.

Quasim, M.A., Karn, A.K., Paul, S., Hmar, E.B.L., Sharma, H.K., 2023. Herbal rodent repellent: a dependable and dynamic approach in defiance of synthetic repellent. B. Nat. Res. Cent. 47, 82. https://doi.org/10.1186/s42269-023-01055-4.

Santamaria, A.E., Olea, P.P., Viňuela, J., Garcia, J.T., 2019. Spatial and seasonal variation in occupation and abundance of common vole burrows in highly disturbed agricultural ecosystems. Eur. J. Wildl. Res. 65, 52. https://doi.org/10.1007/s10344- 019-1286-2.

Singleton, G. R., Brown, P.R., Jacob, J., Aplin, K.P., 2007. Unwanted and unintended effects of culling: A case for ecologically-based rodent management. Integr. Zool. 2, 247–259. https://doi.org/10.1111/j.1749-4877.2007.00067.x.

Stein, G.H.W., 1958. Die Feldmaus. Franckh'sche Verlagshandlung, Stuttgart, Germany.

Suchomel, J., Šipoš, J., Dokulilová, M., Heroldová, M., 2021. Spill over of the common voles from rape fields to adjacent crops. Biologia 76, 1747–1752. https://doi.org/10.2478/s11756-020-00675-9.

Tertil, R., 1977. Impact of the common vole, *Microtus arvalis* (Pallas) on winter wheat and alfalfa crops. EPPO Bull. https://doi.org/10.1111/j.1365-2338.1977.tb02732.x.

Tkadlec, E., Lisicka-Lachnitova, L., Losik, J., Heroldova, M., 2011. Systematic error is of minor importance to feedback structure estimates derived from time series of nonlinear population indices. Popul. Ecol. 53, 495–500. https://doi.org/10.1007/s10144-010-0246-1.

Tobin, M.E., Fall, M.W., 2004. Pest control: rodents. USDA Natl Wildl Res Cent Staff Publ. 67, 1–21.

Tóth, Š., Tancik, J., Šoltysová, B., Porvaz, P. 2023. A case study – the occurrence of pests in stands of newly introduced energy crops in large-scale pilot experiment in conditions of Central Europe. Agriculture (Poľnohospodárstvo) 69 (2), 47–65. DOI: 10.2478/agri-2023-0005.

Wiman, M. R., Kirby, E. M., Granatstein, D. M., Sullivan, T. P., 2009. Cover Crops Influence Meadow Vole Presence in Organic Orchards. HortTechnology 19 (3), 558–562. https://doi.org/10.21273/HORTTECH.19.3.558.

Vencill, W.K., Banks, P.A., 1994. Effects of Tillage Systems and Weed Management on Weed Populations in Grain Sorghum (*Sorghum bicolor*). Weed Sci. 42, 541–547. https://doi.org/10.1017/S0043174500076918.

Williams, S.T., Maree, N., Taylor, P., Belmain, S.R., Keith, M., Swanepoel, L.H., 2018. Predation by small mammalian carnivores in rural agro-ecosystems: An undervalued ecosystem service? Ecosyst. Serv. 30, 362–371. https://doi.org/10.1016/j.ecoser.2017.12.006.

Zapletal M., Obdržálková D., Pikula J., Zejda J., Pikula J., Beklová M., Heroldová M. (2001): Common vole in the Czech Republic (Hraboš polní *Microtus arvalis* (Pallas, 1778) v České republice). Akademické nakladatelství CERM, Brno, s. 128.

Zejda, J., Zapletal, M., Pikula, J., Obdržálková, D., Heroldová, M., Hubálek, Z., 2002. Hlodavci v zemědělské a lesnické praxi, Praha.

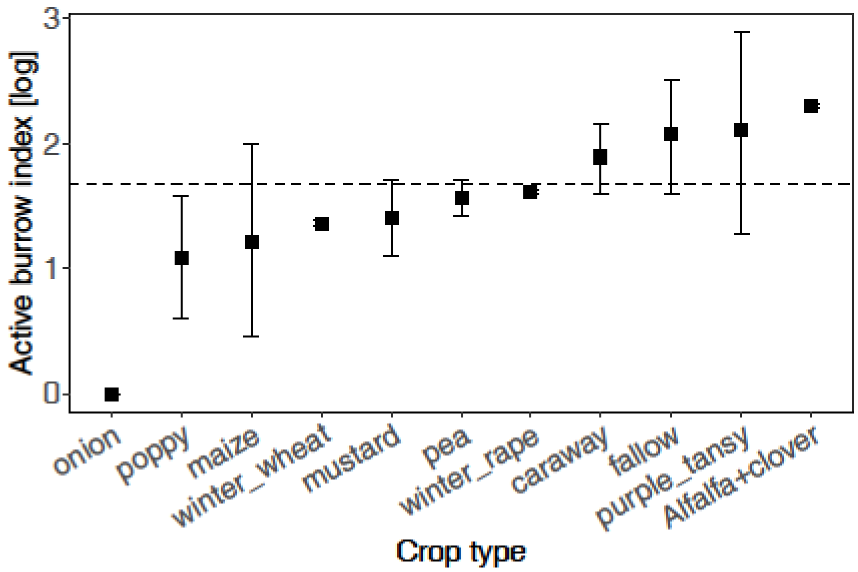


Fig. 1. The average number of active burrows (BI) in stands of the tested crops. The error lines show the 95% confidence intervals and the black squares indicate the arithmetical means. The horizontal dashed line represents the mean BI for all studied crops.

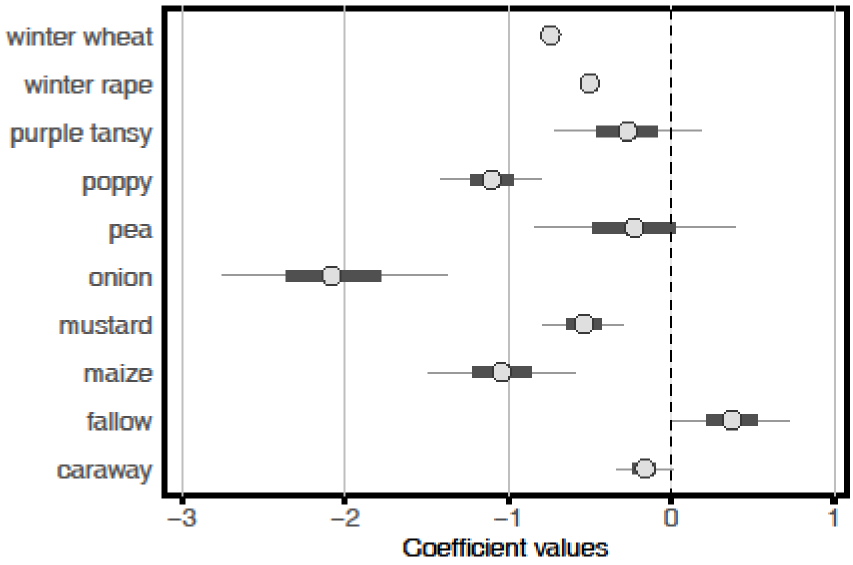


Fig. 2. The interval plot of the coefficients' posterior distribution shows the effect size of different crops relative to the reference crop, Alfalfa + Clover, on the number of active vole burrows (BI) based on MCMC draws. The figure depicts the median estimates of the posterior distribution of coefficients (circle), Bayesian highest density credible intervals (thick gray line), and Bayesian 95% prediction intervals (thin gray line).

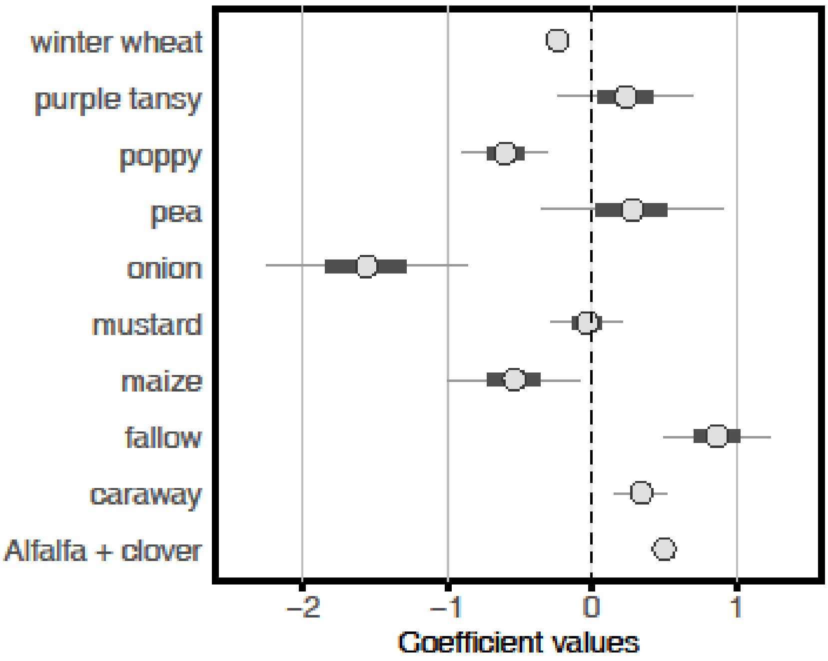


Fig. 3. The interval plot of the coefficients' posterior distribution shows the effect size of different crops relative to the reference crop, winter rape, on the number of active vole burrows (BI) based on MCMC draws. The figure depicts the median estimates of the posterior distribution of coefficients (circle), Bayesian highest density credible intervals (thick gray line), and Bayesian 95% prediction intervals (thin gray line).

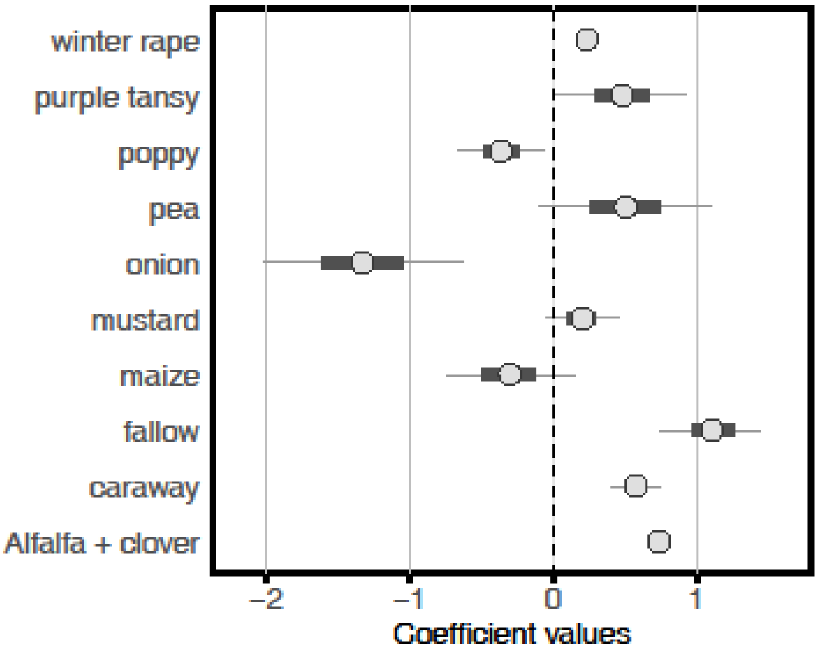


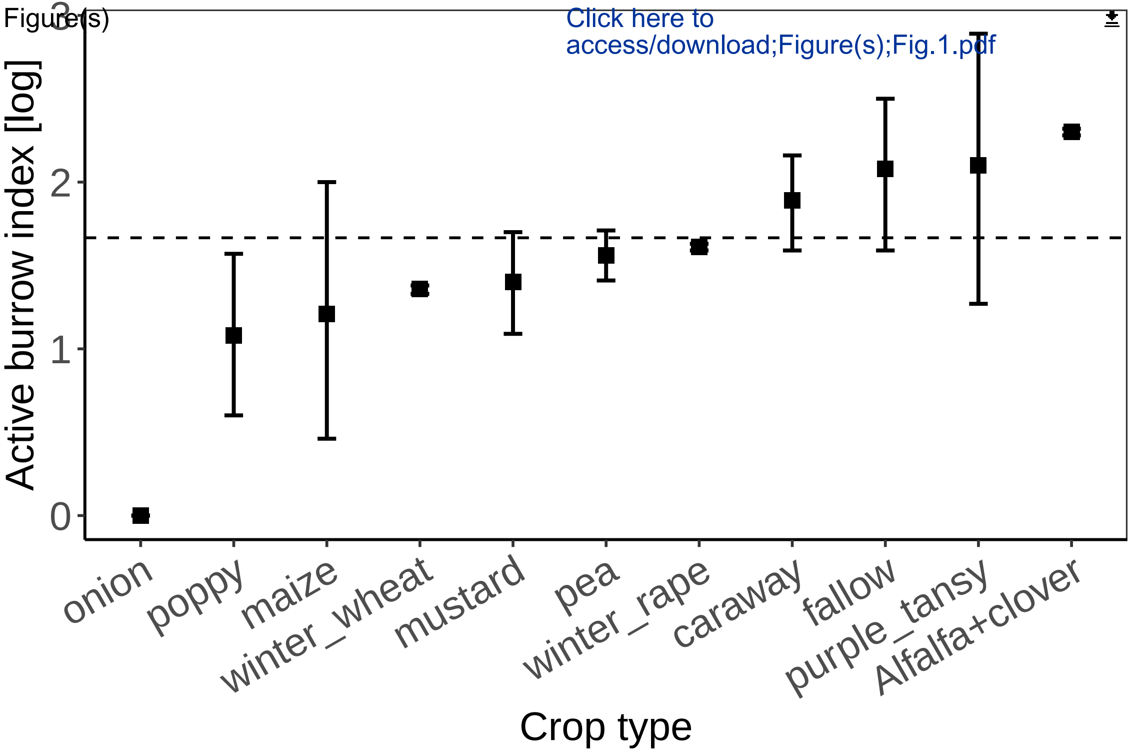
Fig. 4. The interval plot of the coefficients' posterior distribution shows the effect size of different crops relative to the reference crop, winter wheat, on the number of active vole burrows (BI) based on MCMC draws. The figure depicts the median estimates of the posterior distribution of coefficients (circle), Bayesian highest density credible intervals (thick gray line), and Bayesian 95% prediction intervals (thin gray line).

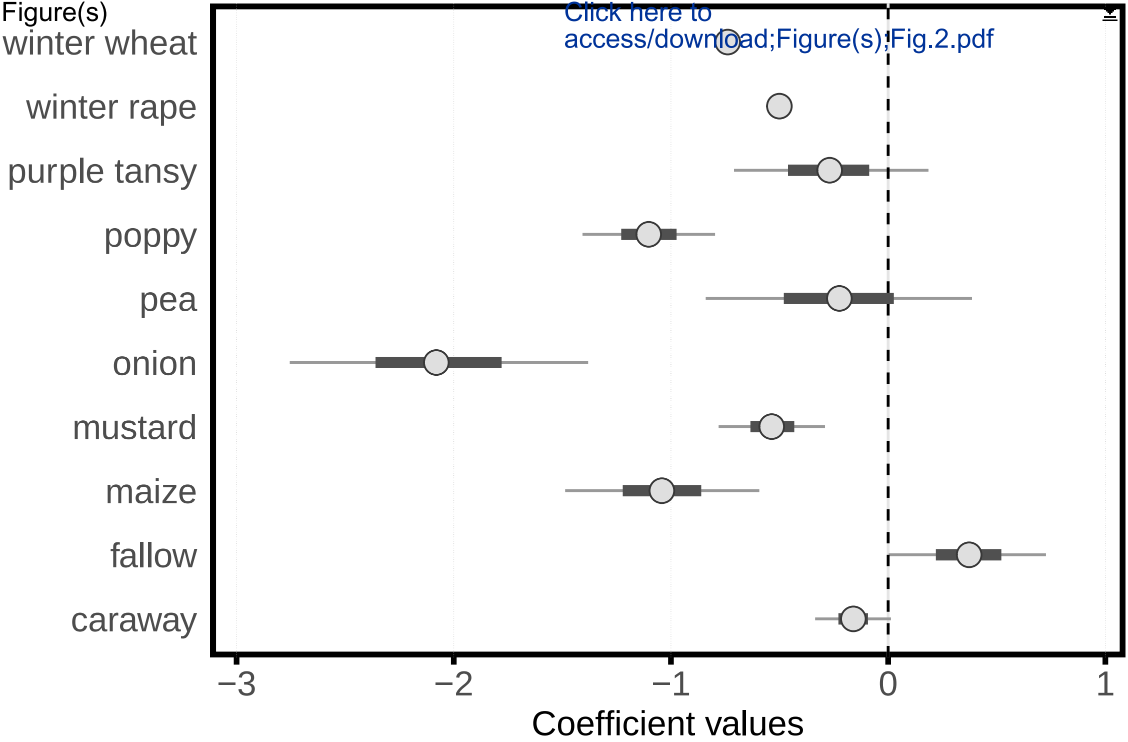
Table 1

The list of tested crops along with the data collection details and burrow index (BI) values.

Crops	**Sampling years**	**Average BI**	**Minimum BI**	**Maximum BI**	**Sampled fields (N)**	**Plant life cycle**
poppy	2000 - 2002, 2004, 2006, 2007, 2009	127	0	1400	**15**	annual
maize	2000,2001,2003,2005,2007,2008	111	0	460	**7**	annual
pea	2000, 2002, 2006, 2012, 2016	38	20	50	**9**	annual
mustard	2001, 2003, 2004, 2005, 2007	64	0	230	**22**	annual
purple tansy	2004, 2005, 2007, 2008	981	0	5610	**7**	annual
onion	2000, 2006, 2007, 2008	0	0	0	**7**	annual (biennial-perennial)
winter rape*	2000 - 2018	176	0	12400	**2704**	biennial
winter wheat*	2000 - 2018	119	0	18400	**2874**	biennial
caraway	2000 - 2006, 2008	485	0	7200	**31**	biennial-perennial
alfalfa+clover*	2000 - 2018	645	0	28000	**1549**	perennial
fallow	2000, 2004, 2006 - 2009	292	0	890	**8**	perennial

* reference crop


3
2
1
0
Active burrow index [log]
onion
poppy
maize
winter_wheat
mustard
pea
winter_rape
caraway
fallow
purple_tansy
Alfalfa+clover
Crop type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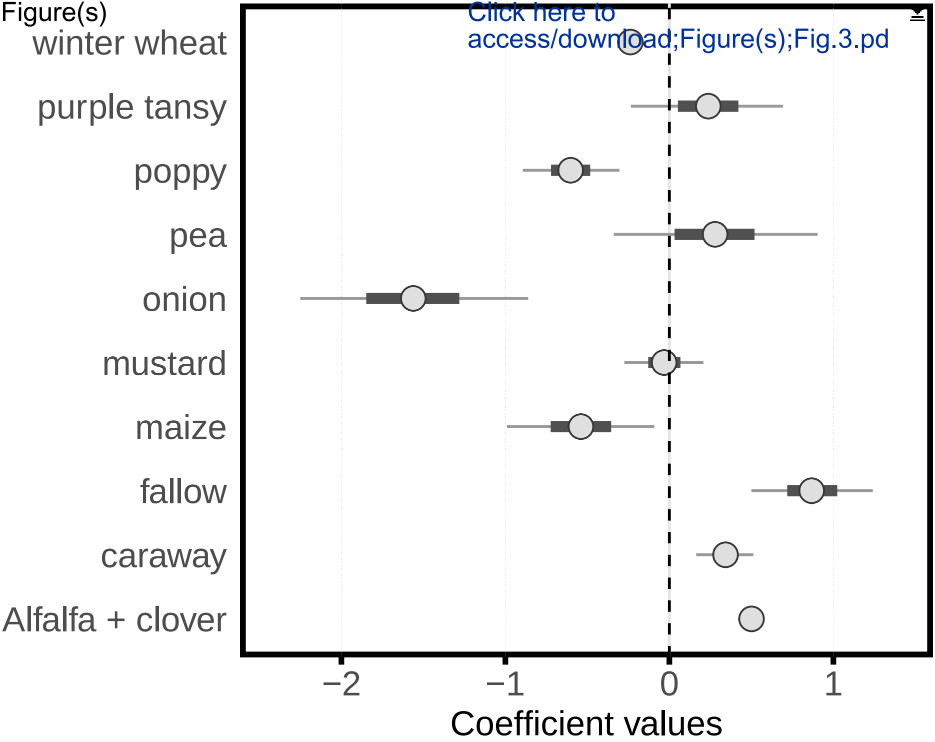
Coefficient values

Figure(s)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Coefficient values

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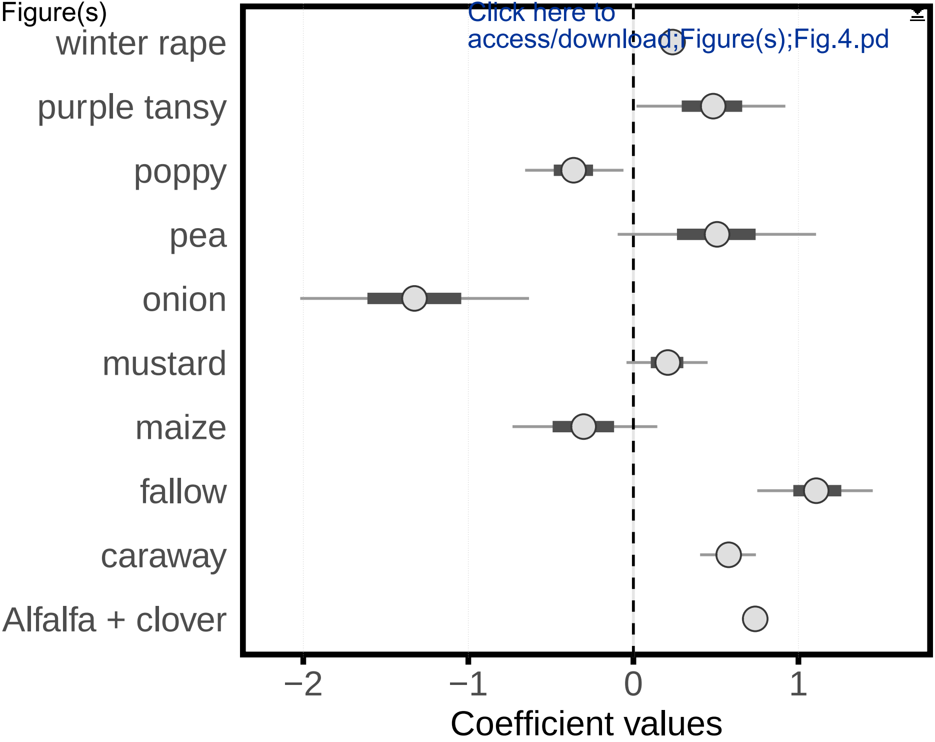
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Coefficient values

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E-component/Supplementary Material

Appendix S2.docx