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Occurrence of archaeophytes in agrophytocoenoses – field survey in the Czech Republic

L. Tyšer, M. Kolářová* and T.T. Hoová

Czech University of Life Sciences Prague, Faculty of Agrobiology, Food and Natural Resources, Department of Agroecology and Crop Production, Kamýcká 129, CZ-165 00 Prague-Suchdol, Czech Republic
*Correspondence: mkolarova@af.czu.cz

Abstract. Archaeophytes are alien plants introduced to the Czech Republic before the year 1500. Their occurrence is strongly connected with agricultural production. The aim of this study was to assess the occurrence of archaeophytes in arable fields in the Czech Republic in terms of applied management systems (conventional and organic farming), crops (winter cereals, spring cereals, wide-row crops) and environmental site conditions at different altitudes. In 2006–2018, a phytocoenological survey was conducted in selected farms across the Czech Republic. Totally, 180 weed species were found, of which 48.89% were considered as archaeophytes (88 species). In view of the invasive status, 5 archaeophytes were considered as invasive, the other 83 species were regarded as naturalized. The net effects of all variables studied on the occurrence of archaeophytes were statistically significant. The majority of the variation was explained by altitude, followed by crop and type of farming. Incidence of archaeophytes increases with an increasing altitude and is also related to their affinity with environmental factors. The highest occurrence of archaeophytes was found in cereals, some species, however, occur more frequently in wide row crops. The higher occurrence of archaeophytes was observed in organically managed fields.

Key words: altitude, cereals, conventional farming, organic farming, weed communities, wide-row crops.

INTRODUCTION

The archaeophytes are a particularly group of species as they constitute 'cultural relics', which testify to the fundamental shift from the nomadic phase in human development, related to hunter-gathering lifestyles, to the sedentary agricultural phase (Comin & Poldini, 2009). These more significant changes came at the beginning of the Neolithic era (around 5700 BC), which was characterized by the beginning and expansion of the planting of cultivated crops accompanied by the first alien weeds (Medvecká et al., 2012). The diaspore pressure, a crucial condition for a successfull invasion, must have been intense and continuous, and facilitated the early invasion of archaeophytes into local communities (Pyšek et al., 2005).

Archaeophytes belong to a group of alien plants, which were introduced by humans either intentionally or unintentionally in different ways. According to the introduction period, alien species can be distinguished into archaeophytes, introduced during ancient times and neophytes, introduced more recently (Preston et al., 2004). As a milestone, the year of the European arrival on the American continent has been considered, i.e. 1492, as since this event voyages of discovery started and therefore possibilities of plants dispersal greatly increased (roughly then this limit is determined by the year of 1500). The definition of archaeophytes, however, is more complicated. Holub & Jirásek (1967) for example define archaeophytes solely as accidentally introduced species. For simplicity and compatibility with the recent usage of the term, we apply it without any relation to whether the given species arrived accidentally or were brought in by humans. We only consider its residence time (species introduced before the year 1500) regardless of the mean of introduction (Pyšek et al., 2002).

Richardson et al. (2000) distinguish between different types of alien plants: casual, naturalized and invasive taxa. Casual alien plants may flourish and even reproduce occasionally in an area, but do not form self-replacing populations, and rely on repeated introductions for their persistence. Naturalized plants reproduce consistently and sustain populations over many life cycles without direct intervention by humans (or in spite of human intervention); they often recruit offspring freely, usually close to adult plants, and do not necessarily invade natural, seminatural or human-made ecosystems. Invasive plants are naturalized plants that produce reproductive offsprings, often in very large numbers, at considerable distances from parent plants, and thus have the potential to spread over a considerable area. This division, however, does not usually address the specific meaning and potential harmfulness of alien taxons. Therefore, environmental and socio-economic impacts of alien species and their appropriate management strategy in the Czech Republic are presented in the so-called Black, Gray and Watch List of Alien Species (Pergl et al., 2016).

The alien flora of the Czech Republic consists of 1,454 taxa, made up by 350 archaeophytes (24.1%) and 1,104 neophytes (75.9%), which represent addition to ca 2,945 native taxa known from the country and form 33.1% of the total plant diversity ever recorded there (Pyšek et al., 2012b). Danihelka et al. (2012) mention that the flora of the Czech Republic includes 3,557 species. Of these, 2,256 species are native, 464 naturalized (228 archaeophytes and 236 neophytes) and 837 casual aliens (62 archaeophytes and 775 neophytes).

The habitats with the greatest proportion of aliens belong to two groups, anthropogenic habitats (arable land, ruderal vegetation, trampled areas) and coastal, littoral and riverine habitats. Neophytes were found commonly in habitats also occupied by archaeophytes. Thus, the number of archaeophytes can be considered as a good predictor of the neophyte invasion risk. However, neophytes had a stronger affinity to wet habitats and disturbed woody vegetation while archaeophytes tended to be more common in dry to mesic open habitats (Chytrý et al., 2008). Archaeophytes occupy more habitats and plots due to longer residence time because they had more time to disperse and adapt (Küzmič & Šilc, 2017). In terms of field conditions, aliens are most common in lowland agricultural and urban areas, whereas they are sparsely represented in mountainous areas. At intermediate elevations, agricultural areas are more invaded than forested areas. General similarity of the invasion maps for archaeophytes and neophytes reflects the high correlation between the occurrence of these two groups of aliens. However, there are some fine-scale differences between them, contrary to the similarity revealed at a coarse scale. For example, neophytes more strongly respond to altitude, being more concentrated in the lowlands than archaeophytes. Also, neophytes more heavily invade river corridors than archaeophytes (Chytrý et al., 2009; Pyšek et al., 2012a).

Representation of aliens in agrophytocoenoses is related to the farming intensity and a crop structure. Medvecká et al. (2014) support that two of the main factors affecting the invasibility of plant communities are disturbance and an excess of nutrients. Intensification of agriculture (e.g. large amounts of fertilizer) may promote invasion of neophytes (Soukup et al., 2004; Kovács-Hostyánszki et al., 2011). Lososová & Cimalová (2009) stated that cereal fields and root crop fields were richer in archaeophytes and neophytes, respectively. Archaeophytes are common in old crops introduced with the beginning of agriculture (cereals), but are poorly represented in rather recently introduced crops (rape, maize), where neophytes are most numerous (Pyšek et al., 2005).

Neophytes have been progressively more numerous in arable fields and their proportion significantly increased during the second half of the 20th century (Pyšek et al., 2003, 2005; Šilc & Čarni, 2005). Archaeophytes have been shifting from anthropogenous to more natural habitats in recent time (Medvecká et al., 2014; Küzmič & Šilc, 2017). Lososová et al. (2004) indicate a decline in archaeophytic annuals (e.g. *Papaver argemone*, *Neslia paniculata*, *Raphanus raphanistrum*) and an increase in neophytes. Comin & Poldini (2009) present that those archaeophytes that are declining or extinct have specialised pollination and dispersal, brevity of phenophases, S- and/or R-type functional strategies, and the ability to colonise predominantly segetal habitats. Some of them have either virtually disappeared from the European scene or have become very rare, including *Agrostemma githago*, *Silene linicola* and *Turgenia latifolia*.

So far, the question of the representation of archaeophytes in agrophytocoenoses has been only sparsely addressed in the Czech Republic; therefore, the objective of this study is to assess the current occurrence of archaeophytes in arable fields in representative areas of the Czech Republic based on the following criteria (i) applied management systems (farming type - conventional and organic), (ii) crop type (winter cereals, spring cereals, wide-row crops), and (iii) environmental site conditions (temperature, precipitation, soil type) integrated with altitude.

MATERIALS AND METHODS

Study area

In 2006–2018, a phytocoenological survey was carried out on selected farms across the Czech Republic at various climate and soil conditions. The farms were selected based on three criterals: (1) applied management systems: conventional farms (common chemical weed control) and organic farms (using methods according to an appropriate valid legislation without applying herbicides and with at least 2 years of organic management practices) were chosen; (2) crop type: winter cereals (winter wheat, winter barley, rye, spelt, triticale), spring cereals (spring barley, oat, naked oat, spring wheat, spring rye, spring triticale) and wide-row spring crops (sugar beet, potatoes, maize, oil pumpkin, feeding carrots, fodder beet, beet-root, sunflower, onion) were observed; (3) elevation gradient: we selected areas of which the altitude varied between 170 and 681 m above sea level. In total, 320 phytocoenological relevés were recorded (Fig. 1), 163 thereof represented conventionally farmed fields and 157 organic fields. Concerning crops, 107 relevés were recorded in winter cereals, 108 in spring cereals and 105 in wide-row crops. Weediness was assessed in June and July in cereals and in late July, August, September and at the beginning of October in wide row crops. With respect to the altitude, 116 relevés were recorded at altitudes lower than 250 m, 92 relevés at 250–350 m, and 112 relevés at levels higher than 350 m.

Evaluation

The cover was visually estimated by means of the nine-degree Braun-Blanquet scale (Braun-Blanquet, 1964; modified by Barkman et al., 1964). The size of one phytocoenological relevé was 100 m^2, and each relevé was performed in the central part of an individual field. Fungi, non-vascular plants and self-seeded seedlings of trees were not included into the evaluation. The native/alien status was classified for each taxon (Pyšek et al., 2012b). The nomenclature followed that of Kubát et al. (2002).

Data analysis

The frequencies of individual species were calculated, while the presence of the species in a relevé only was taken into account for these calculations. The total frequency (%) is calculated as the proportion of the sum of presences of archeophytes in relevés taken in the frame of individual factors to the sum of presences of archeophytes in all relevés.

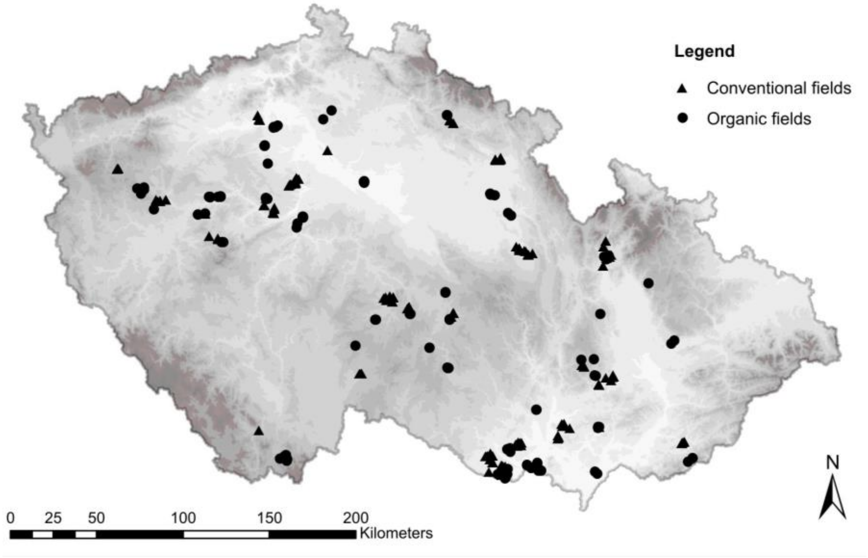

Figure 1. Map of the Czech Republic showing recorded relevés.

The archaeophyte occurrence in different farming types, crops and altitudes was analysed by multivariate analyses in the CANOCO 4.5 software (ter Braak & Šmilauer, 2002). Values of the Braun-Blanquet scale were transformed to an ordinal scale 1–9 (van der Maarel, 1979). As the gradients on the first canonical axis (4.906 SD units) in the compositional turnover in a detrended correspondence analysis (DCA) were long, the canonical correspondence analysis (CCA) was chosen as a direct analysis. In the CCA, net effects of all explanatory variables on archaeophytes occurrence were determined. As explanatory variables, the type of farming (conventional, organic), crop (winter cereals, spring cereals and wide-row crops) and altitude were used. After an exclusion of the effects shared with other variables, the net effects of individual variables were obtained and tested using partial CCAs, when only one explanatory variable was used and the other variables were used as covariables (Lososová et al., 2004). The ratio of a certain canonical eigenvalue to the sum of all eigenvalues (total inertia) was used to estimate the proportion of the explained variation (Borcard et al., 1992). The effects were evaluated using Monte Carlo permutation tests (ter Braak & Šmilauer, 2002) for the first or all canonical axes (999 permutations were used).

RESULTS AND DISCUSSION

In total, 180 weed species were found (volunteer crops were not included). Among the observed species, 48.89% were considered as archaeophytes (88 species), 43.33% as apophytes (78 species) and 7.78% as neophytes (14 species). Pyšek et al. (2012b) state that the alien flora of the Czech Republic forms 33.10% of the total plant diversity. Danihelka et al. (2012) add a similar percentage of alien flora representation (36.6%). The high proportion of alien flora in our research (56.67%) is related to the character of studied areas as they have been under permanent disturbance and human (farmer) influence each year (Chytrý et al., 2008). The highest proportion of alien species occurs on arable land (Küzmič & Šilc, 2017). This finding correlates with the data reported by Holec et al. (2008), who mentioned approximately 30% of apophytes, 60% of archaeophytes, and 10% of neophytes among arable weeds occurring in the Czech Republic. According to Lososová & Simonová (2008), the representation of archeophytes, natives and neophytes in weed vegetation in Moravia is 45%, 49% and 6%, respectively.

Compared to neophytes, archaeophytes occurred in agrophytocoenoses more frequently. This fact could be explained mainly by the character of plants accompanying agricultural crops already spreading since the Neolithic due to move of agricultural production from Middle East and Mediterranean areas to northern countries. The occurrence of this big group of plants stays restricted primarily to arable land and gardens (Arlt et al., 1991). Moreover, neophytes had much less time for their spread into agrophytocoenoses.

Species frequencies in relation to individual factors are shown in Table 1.

Table 1. Species frequencies (%) related to studied factors

Species	All	Type of farming		Crop			Altitude (m.a.s.l.)		
		conv	org	WC	SC	WR	< 250	250–350	> 350
Fallopia convolvulus	67.50	55.21	80.25	73.83	82.41	45.71	55.17	64.13	83.04
Cirsium arvense	55.00	40.49	70.06	52.34	56.48	56.19	53.45	55.43	56.25
Tripleurospermum inodorum	49.69	28.83	71.34	52.34	54.63	41.90	37.93	48.91	62.50
Capsella bursa-pastoris	44.38	28.83	60.51	36.45	50.93	45.71	25.86	35.87	70.54
Thlaspi arvense	39.38	17.18	62.42	28.97	50.00	39.05	25.86	41.30	51.79
Convolvulus arvensis	28.75	23.31	34.39	24.30	23.15	39.05	50.00	18.48	15.18
Anagallis arvensis	26.56	17.18	36.31	20.56	45.37	13.33	23.28	32.61	25.00
Euphorbia helioscopia	25.63	17.79	33.76	19.63	36.11	20.95	14.66	35.87	28.57
Myosotis arvensis	25.31	9.82	41.40	30.84	30.56	14.29	0.86	26.09	50.00

Table 1 (continued)

Lamium purpureum	25.31	18.40	32.48	19.63	36.11	20.00	9.48	28.26	39.29
Echinochloa crus-galli	24.69	23.93	25.48	11.21	16.67	46.67	42.24	27.17	4.46
Apera spica-venti	22.81	18.40	27.39	42.99	21.30	3.81	19.83	21.74	26.79
Geranium pusillum	21.25	17.18	25.48	16.82	21.30	25.71	6.03	16.30	41.07
Silene noctiflora	18.13	9.82	26.75	14.02	33.33	6.67	21.55	27.17	7.14
Veronica arvensis	17.81	7.36	28.66	28.04	16.67	8.57	4.31	16.30	33.04
Avena fatua	17.81	18.40	17.20	14.95	25.00	13.33	11.21	23.91	19.64
Fumaria officinalis	14.69	11.04	18.47	6.54	24.07	13.33	4.31	11.96	27.68
Sonchus arvensis	14.38	3.68	25.48	11.21	15.74	16.19	5.17	9.78	27.68
Lamium amplexicaule	14.38	10.43	18.47	13.08	19.44	10.48	12.93	13.04	16.96
Papaver rhoeas	14.06	5.52	22.93	20.56	15.74	5.71	11.21	17.39	14.29
Veronica polita	13.44	10.43	16.56	11.21	18.52	10.48	12.93	19.57	8.93
Sonchus asper	11.56	7.98	15.29	5.61	18.52	10.48	12.93	8.70	12.50
Erodium cicutarium	10.63	2.45	19.11	7.48	10.19	14.29	2.59	4.35	24.11
Lactuca serriola	10.31	3.68	17.20	15.89	12.04	2.86	12.93	10.87	7.14
Setaria pumila	10.00	3.68	16.56	4.67	9.26	16.19	20.69	7.61	0.89
Atriplex patula	9.69	8.59	10.83	7.48	9.26	12.38	6.03	7.61	15.18
Lycopsis arvensis	9.06	2.45	15.92	2.80	12.04	12.38	2.59	5.43	18.75
Lapsana communis	9.06	4.29	14.01	10.28	12.04	4.76	0.00	5.43	21.43
Descurainia sophia	8.75	2.45	15.29	13.08	5.56	7.62	13.79	11.96	0.89
Centaurea cyanus	8.75	2.45	15.29	11.21	12.04	2.86	0.00	3.26	22.32
Solanum nigrum	8.75	9.20	8.28	1.87	7.41	17.14	14.66	8.70	2.68
Spergula arvensis	8.44	1.84	15.29	0.93	13.89	10.48	0.00	4.35	20.54
Consolida regalis	7.81	4.91	10.83	15.89	4.63	2.86	7.76	11.96	4.46
Sinapis arvensis	7.81	2.45	13.38	5.61	11.11	6.67	9.48	8.70	5.36
Matricaria recutita	7.50	0.61	14.65	5.61	12.04	4.76	0.86	6.52	15.18
Galium spurium	7.19	2.45	12.10	14.02	5.56	1.90	5.17	13.04	4.46
Geranium dissectum	6.88	4.91	8.92	10.28	9.26	0.95	1.72	6.52	12.50
Vicia angustifolia	6.56	0.61	12.74	8.41	4.63	6.67	1.72	4.35	13.39
Mercurialis annua	5.00	4.91	5.10	1.87	4.63	8.57	6.03	9.78	0.00
Raphanus raphanistrum	4.69	0.61	8.92	3.74	5.56	4.76	2.59	5.43	6.25
Arctium tomentosum	4.38	2.45	6.37	5.61	4.63	2.86	4.31	8.70	0.89
Euphorbia exigua	4.38	2.45	6.37	6.54	5.56	0.95	4.31	7.61	1.79
Setaria viridis	3.75	0.61	7.01	0.93	1.85	8.57	6.90	4.35	0.00
Lathyrus tuberosus	3.13	2.45	3.82	6.54	2.78	0.00	2.59	6.52	0.89
Papaver dubium	2.81	0.61	5.10	7.48	0.00	0.95	0.86	4.35	3.57
Anthemis arvensis	2.81	0.00	5.73	1.87	1.85	4.76	0.00	3.26	5.36
Veronica agrestis	2.81	0.61	5.10	1.87	2.78	3.81	0.00	1.09	7.14
Malva neglecta	2.81	2.45	3.18	1.87	0.00	6.67	4.31	3.26	0.89
Conium maculatum	2.81	3.68	1.91	3.74	2.78	1.90	6.03	2.17	0.00
Sonchus oleraceus	2.81	3.68	1.91	1.87	2.78	3.81	3.45	3.26	1.79
Veronica hederifolia	2.81	1.84	3.82	1.87	5.56	0.95	2.59	2.17	3.57
Atriplex sagittata	2.50	1.23	3.82	1.87	4.63	0.95	3.45	2.17	1.79
Microrrhinum minus	2.50	0.00	5.10	1.87	3.70	1.90	0.00	4.35	3.57
Neslia paniculata	2.50	0.00	5.10	0.00	2.78	4.76	0.86	3.26	3.57
Erysimum cheiranthoides	2.50	0.61	4.46	0.93	2.78	3.81	4.31	1.09	1.79

Table 1 (continued)

Silene latifolia subsp. *alba*	2.19	1.23	3.18	0.93	3.70	1.90	0.00	5.43	1.79
Sisymbrium officinale	2.19	0.00	4.46	0.93	0.00	5.71	1.72	2.17	2.68
Viola tricolor	2.19	0.61	3.82	1.87	4.63	0.00	0.86	0.00	5.36
Digitaria sanguinalis	1.88	0.00	3.82	0.00	0.00	5.71	5.17	0.00	0.00
Linaria vulgaris	1.88	0.00	3.82	2.80	1.85	0.95	0.00	1.09	4.46
Stachys annua	1.88	0.61	3.18	0.93	2.78	1.90	1.72	3.26	0.89
Hyoscyamus niger	1.88	1.84	1.91	0.93	4.63	0.00	3.45	2.17	0.00
Carduus acanthoides	1.56	0.61	2.55	0.00	3.70	0.95	2.59	1.09	0.89
Fumaria vaillantii	1.56	0.61	2.55	1.87	1.85	0.95	1.72	2.17	0.89
Senecio vulgaris	1.56	0.61	2.55	0.00	0.93	3.81	2.59	1.09	0.89
Portulaca oleracea	1.56	0.61	2.55	0.00	0.93	3.81	3.45	1.09	0.00
Chenopodium pedunculare	1.25	0.00	2.55	0.00	0.00	3.81	1.72	0.00	1.79
Bromus sterilis	1.25	2.45	0.00	1.87	0.93	0.95	0.00	2.17	1.79
Fumaria rostellata	0.94	0.61	1.27	0.00	2.78	0.00	0.00	0.00	2.68
Sherardia arvensis	0.94	0.00	1.91	0.93	1.85	0.00	0.00	1.09	1.79
Valerianella dentata	0.94	0.00	1.91	1.87	0.93	0.00	0.00	1.09	1.79
Adonis aestivalis	0.94	1.84	0.00	2.80	0.00	0.00	0.86	2.17	0.00
Anthemis austriaca	0.63	0.00	1.27	0.93	0.93	0.00	0.86	1.09	0.00
Ranunculus arvensis	0.63	0.00	1.27	1.87	0.00	0.00	0.00	0.00	1.79
Setaria verticillata	0.63	0.00	1.27	0.00	0.00	1.90	1.72	0.00	0.00
Anagallis foemina	0.63	0.61	0.64	0.93	0.93	0.00	0.00	2.17	0.00
Papaver argemone	0.63	1.23	0.00	0.93	0.00	0.95	0.00	0.00	1.79
Armoracia rusticana	0.31	0.00	0.64	0.93	0.00	0.00	0.00	1.09	0.00
Camelina microcarpa	0.31	0.00	0.64	0.93	0.00	0.00	0.00	1.09	0.00
Cardaria draba	0.31	0.00	0.64	0.00	0.93	0.00	0.00	1.09	0.00
Coronopus squamatus	0.31	0.00	0.64	0.00	0.00	0.95	0.00	1.09	0.00
Diplotaxis muralis	0.31	0.00	0.64	0.93	0.00	0.00	0.00	1.09	0.00
Euphorbia falcata	0.31	0.00	0.64	0.00	0.93	0.00	0.00	1.09	0.00
Lithospermum arvense	0.31	0.00	0.64	0.93	0.00	0.00	0.00	0.00	0.89
Onopordum acanthium	0.31	0.00	0.64	0.93	0.00	0.00	0.86	0.00	0.00
Crepis tectorum	0.31	0.00	0.64	0.00	0.00	0.95	0.00	0.00	0.89
Bromus hordeaceus	0.31	0.61	0.00	0.93	0.00	0.00	0.00	0.00	0.89
Urtica urens	0.31	0.61	0.00	0.00	0.93	0.00	0.86	0.00	0.00
The total frequency (%)	100.00	31.22	68.78	31.45	39.36	29.19	28.54	29.16	42.30

conv – conventional farming; org – organic farming; WC – winter cereals; SC – spring cereals; WR – wide-row crops.

The average number of archaeophytes species per 1 relevé in different types of farming, crops and altitudes are shown in Fig. 2.

According to Kropáč (1988), the highest frequencies can be found for eurycoenotic species, i. e. they occur in most weed communities of cereals and wide-row crops as constant dominants and can also be found outside of arable land as ruderal species, e. g. *Fallopia convolvulus* (67.50%), *Tripleurospermum inodorum* (49.69%), *Cirsium arvense* (55.00%), *Convolvulus arvensis* (28.75%) and others. Their high appearance in agrophytocoenoses is relatively stable (Lososová & Simonová, 2008).

With respect to invasion status proposed by Pyšek et al. (2012b), 5 archaeophytes were considered invasive (*Cirsium arvense*, *Echinochloa crus-galli*, *Conium maculatum*, *Atriplex sagittata*, *Portulaca oleracea*). The other 83 species were regarded as naturalized. An absolutely large proportion of naturalized species is related to the long term occurrence in our region. Archaeophytes, which would not have become naturalized could hardly be recorded in our times (Pyšek et al., 2002). The absence of casual archaeophytes could be explained by the fact that volunteer crops were not included into this analysis. *Cirsium arvense* is classified as one of the most troublesome and invasive plants worldwide (Tiley, 2010; Guggisberg et al., 2012). In Europe it was considered the third most harmful agricultural weed in the past (Schroeder et al., 1993). Also, *Echinochloa crus-galli* belongs to the most serious weeds in the world (Holm et al., 1991). Under conditions of the Czech Republic, it has been spreading together with an enhanced growing of silage corn and an increasing temperature at higher altitudes (Jursík et al., 2011). Another important invasive weed species is *Conium maculatum* (Vetter, 2004) which currently expands in ruderal areas and enters also field crops (Brant et al., 2008; Jursík et al., 2011). The most remarkable increase of *Atriplex sagittata* starts after the Second World War. The species is closely confined to ruderal sites and habitats facilitating transport (Mandák & Pyšek, 1998). On fields, it occurs only to a limited extent, it spreads from adjacent ruderal

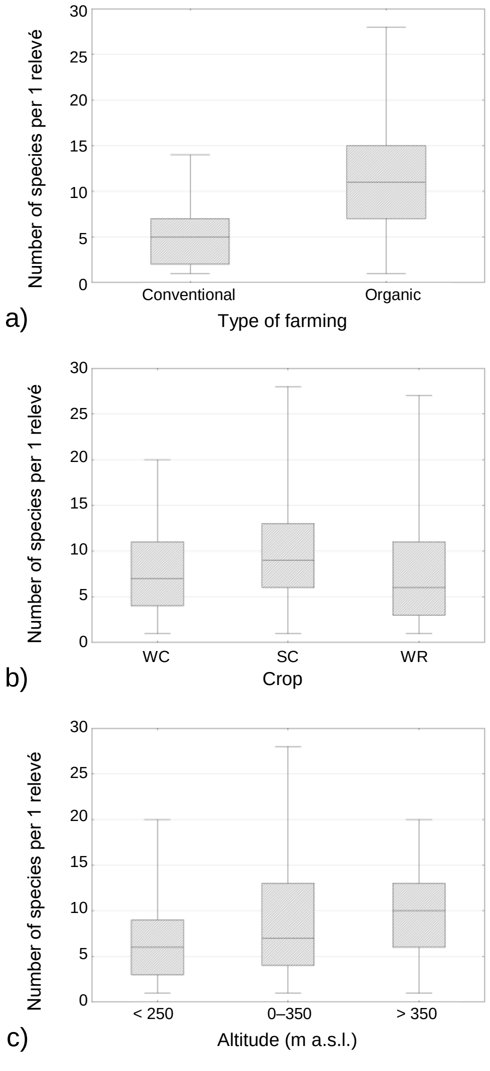

Figure 2. Number of species per 1 relevé in different types of farming (a), crops (b) and altitudes (c). Box and whisker plot: median, 25th to 75th percentile, minimum and maximum value.

areas, roads and dunghills to other sites.*Portulaca oleracea* belongs to the most harmful world weeds (Holm et al., 1991). In our region, it has started spreading into warm areas and causing increasing problems in vegetables.

Pergl et al. (2016) mention invasive archaeophytes described above also. They classify the species *Cirsium arvense, Echinochloa crus-galli, Conium maculatum, Portulaca oleracea* and also *Setaria verticillata* as the Species group BL 3 with predominantly moderate environmental and socio-economic impacts. The recommended strategy for these species is a stratified approach balancing between the local needs and the available resources for eradication. Considering large spread and agricultural harmfulness of *Cirsium arvense* and *Echinochloa crus-galli* (Table 1), there is a need of their regular eradication using all available methods (Jursík et al., 2011). *Conium maculatum, Portulaca oleracea, Setaria verticillata* usually occur only locally and at suitable environmental and farming conditions, therefore, methods of their regulation will depend on a specific situation.

Besides archaeophytes mentioned, there is a big number of neophytes which can be found in the Species group BL 3 (for example *Amaranthus powellii, Amaranthus retroflexus, Conyza canadensis, Galinsoga quadriradiata* and others). Considering their relatively recent introduction to our country, their spread is of a contemporary issue. Also these species are already significantly represented on arable land of the Czech Republic (Kolářová et al., 2017) and their eradication is needed.

Only *Atriplex sagittata* belongs to the Grey List (Pergl et al., 2016) with limited environmental and socio-economic impacts and with a management strategy tolerance. As *Atriplex sagittata* occur only rarely on arable land, normally it is not necessary to take it inot account during weed control strategies.

No any archaeophytes found are listed in the the official list of alien expansive weeds (sensu Jehlík, 1998). This absence arises from the fact that especially neophytes newly spreading in our country occur on this list.

The occurrence of archaeophytes in agrophytocoenoses may vary over years. Farm management practices and climatic changes have an influence on the composition of weed spectra. With the advent of intensive agriculture, the richness of weed flora and the weed vegetation consisting of specialized annual archaeophytes declined (Holzner, 1982; Lososová, 2003; Comin & Poldini, 2009). Also Pyšek et al. (2005) mention that on a half-century time scale (1955–2000), numbers of archaeophytes have significantly decreased in sample plots on arable land in the Czech Republic. Many archaeophytes were strongly connected to the traditional way of farm management and did not survive modern growing technologies (crop rotation, effective seed cleaning, fertilization, herbicide application, etc.). Examples are species like *Agrostemma githago, Camelina alyssum, Lolium remotum* and *temulentum* or *Scandix pecten-veneris* (Korneck et al., 1998; Schumacher & Schick, 1998). They are listed on the Red Lists of endangered species of the Czech Republic and of neighbour countries (Grulich, 2012; Eliáš et al., 2015). For some archaeophytes, however, even the conditions of intensive farming were suitable and they remained important weeds on arable land, e. g. species from the *Poaceae* family such as *Apera spica-venti*, *Avena fatua* and *Echinochloa crus-galli*. Grass weeds are more difficult to control due their relation with cereals and due to the long period in which mainly herbicides against dicotyledonous were used (Kühn, 1987). In most field crops the occurrence of some grass weeds increased even after the introduction of specific post-emergence grass herbicides (ACCase inhibitors). The main reasons for this increase are crops favourable for grass weeds, reduced tillage, early sowing time, high nitrogen levels, and in some regions the development of herbicide resistant populations (Hurle, 1993; Soukup et al., 2006).

Many archaeophytes, which were decreasing in the last decades, have reacted sensitively to changes in farming systems related to society transformation in the Czech Republic after 1989 (disintegration of the socialist large-scale farming, creation of new economic entitites, low financial inputs into agriculture like limited use of fertilizers and pesticides). Nowadays they increase their abundance again, even causing economic harm. Some factors causing this change are different soil cultivation (*Bromus sterilis*), increasing cropping areas of winter crops and delayed time of weed control to autumn (*Centaurea cyanus*, *Papaver rhoeas*, *Fallopia convolvulus*, *Adonis aestivalis*), low intensity of management in field surrounding areas (*Conium maculatum*) (Soukup et al., 2004). An interesting history can be seen for example at the species *Centaurea cyanus*. This archaeophyte was one of the most abundant cereal weeds in the Czech Republic still in the mid-20th century. In folowing decades, however, it considerably decreased due to an agriculture intensification and in the 1970s and 1980s it belonged to endangered species. In recent years, especially in connection with the expanding growing of winter oilseed rape, it has been experiencing its renaissance and, especially in middle altitudes, it is again becoming an economically important weed (Jursík et al., 2009). In a recent version of the Red List of Endangered Plants (Grulich, 2012) it is no longer recorded among endangered species.

Besides the farm management practices, the climatic changes affect the composition of weed spectra as well. Over the past decades, climate change has induced transformation in the weed flora of arable ecosystems. For instance, thermophile weeds, late-emerging weeds, and some opportunistic weeds have become more abundant in cropping systems. Also some late emergers archaeophytes such as *Echinochloa crus-galli* and *Setaria* spp. have expanded their distribution range (Peters et al., 2014).

The net effects of all studied variables (type of farming, crop, altitude) on the occurrence of archaeophytes were found as statistically significant (Table 2). All together, these variables explained 6.81% of the total variation in the studied species data. The majority of the variability was explained by altitude (3.01%), followed by crop (2.66%) and type of farming (1.06%). Lososová et al. (2004) found the primary role of altitude and associated climatic factors in weed species composition. They stressed that human-made habitats consisting of a large proportion of alien species and strongly depending on farm management, seems to be more affected by primary environmental factors than by human activities.

Table 2. Net effects of explanatory variables on the occurrence of archaeophytes

	Eigenvalue	%	*F*-ratio	*p*-value
All	0.522	6.81	5.617	0.001
Type of farming	0.081	1.06	3.464	0.001
Crop	0.204	2.66	4.382	0.001
Altitude	0.230	3.01	9.885	0.001

Eigenvalue – sum of all canonical eigenvalues (total inertia = 7.656); *%* – percentage of explained variance; *F-ratio* for the test of significance of all (first) canonical axes; *p-value* – corresponding probability value obtained using the Monte Carlo permutation test (999 permutations).

In Table 1, Fig. 2 and in the ordination diagram representing the occurrence of archaeophytes in different types of farming (Fig. 3) the higher occurrence of archaophytes in organic areas is clearly visible. Organic farming may be less intensive and aggressive to the adjacent weed flora than a massive pressure of herbicides in conventional systems. In addition, diverse crop rotations in organic farming support biodiversity more than narrow crop rotations in conventional systems (Bengtsson et al., 2005). Due to this fact, in organic areas many sensitive, descending and rare species may occur. Organic fields serve then as reservoirs of today rare archaeophytes and can play a certain role in the frame of saving programs for endangered species (Albrecht & Mattheis, 1998).

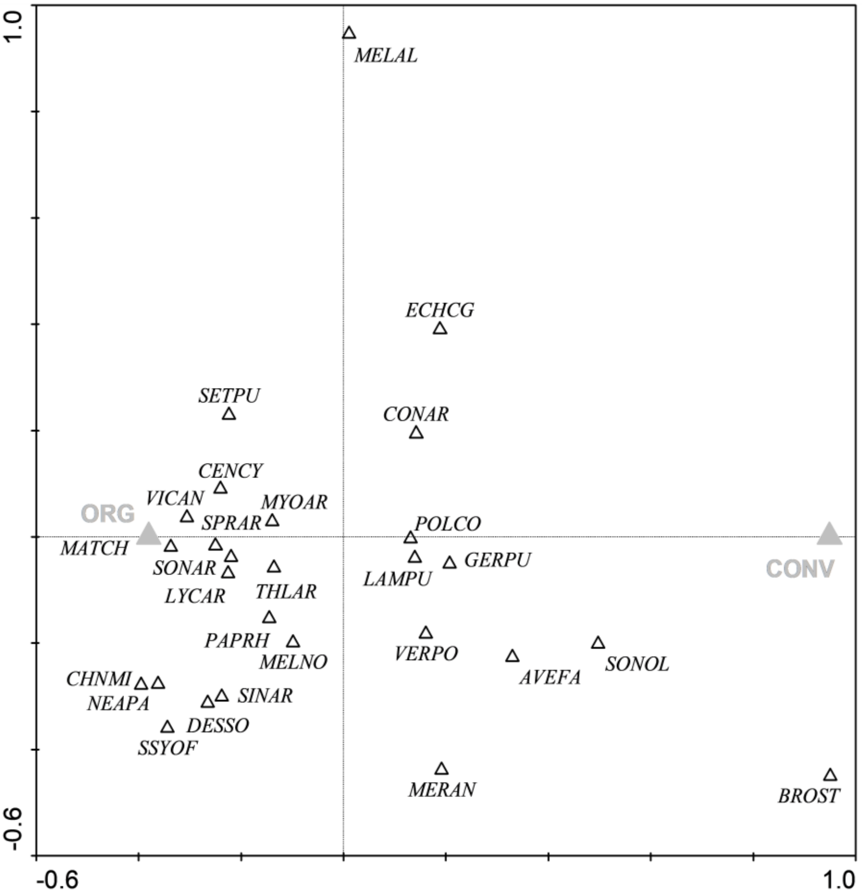

Figure 3. Ordination diagram, *pCCA*. Occurrence of archaeophytes in different types of farming. Minimum species fit 2% – 27 species from 88.

Abbreviations: CONV – conventional farming; ORG – organic farming; AVEFA – *Avena fatua*; BROST – *Bromus sterilis*; CENCY – *Centaurea cyanus*; CHNMI – *Microrrhinum minus*; CONAR – *Convolvulus arvensis*; DESSO – *Descurainia sophia*; ECHCG – *Echinochloa crus-galli*; GERPU – *Geranium pusillum*; LAMPU – *Lamium purpureum*; LYCAR – *Lycopsis arvensis*; MATCH – *Matricaria recutita*; MELAL – *Silene latifolia* subsp. *alba*; MELNO – *Silene noctiflora*; MERAN – *Mercurialis annua*; MYOAR – *Myosotis arvensis*; NEAPA – *Neslia paniculata*; PAPRH – *Papaver rhoeas*; POLCO – *Fallopia convolvulus*; SETPU – *Setaria pumila*; SINAR – *Sinapis arvensis*; SONAR – *Sonchus arvensis*; SONOL – *Sonchus oleraceus*; SPRAR – *Spergula arvensis*; SSYOF – *Sisymbrium officinale*; THLAR – *Thlaspi arvense*; VERPO – *Veronica polita*; VICAN – *Vicia angustifolia*.

Just a few species occur with a higher frequency and affinity to the conventional type of farming. They are often tough and harmful weed taxons, often with an important economic significance. One of them is *Bromus sterilis*, which has been recently strongly spreading on agricultural farms applying shallow or no tillage soil management systems. As it is an overwintering weed species, a high proportion of cash winter crops (winter wheat, winter oil seed rape) in reduced crop rotations and also its tolerance to herbicides may be responsible (Valičková et al., 2017).

As seen in Table 1 and Fig. 2, the highest share of archaeophytes can be found in cereals, namely in spring ones. This is confirmed by data of Lososová & Cimalová (2009), that cereal fields were richer in archaeophytes and root crop fields were richer in neophytes. Archaeophytes are common in old crops introduced with the beginning of agriculture (cereals), but are poorly represented in rather recently introduced crops (oilseed rape, maize) (Pyšek et al., 2005). Our ordination diagram showing the occurrence of archaeophytes in different crops (Fig. 4) present species with the highest affinity to crops studied. From the diagram, it is apparent that archaeophytes do not have a relation only to cereals, but many of them occur more in wide-row crops, namely summer annual species (e. g. millet grasses – *Echinochloa crus-galli, Setaria spp., Digitaria sanguinalis; Solanum nigrum; Portulaca oleracea; Chenopodium pedunculare*), which have a character of root crops, vegetables and other wide-row crops (Jursík et al., 2011).

From the table of species frequencies (Table 1) and number of archaeophytes species per 1 relevé (Fig. 2) we can see an increasing occurrence of archaeophytes with an increasing altitude (as a factor representing different climatic and soil conditions like precipitation, temperature, soil type, etc.). Also, the ordination diagram displaying the occurrence of archaeophytes at different altitudes (Fig. 5), proves an increase in the occurrence of archaeophytes along the altitude axis. From our results, we can conclude then, that most archaeophytes unlike neophytes (Jehlík, 1998; Chytrý et al., 2009; Pyšek et al., 2012a; Kolářová et al., 2017) frequently occur in higher altitudes and in many places they reach even the upper border of arable land in the Czech Republic. Archaeophytes occupy more habitats and plots due to a longer residence time because they had more time to disperse and adapt (Küzmič & Šilc, 2017). Pyšek et al. (2011) has shown that higher altitudes were increasingly invaded by alien species in the last 250 years as a consequence of increasing anthropogenic disturbances, higher propagule pressure and climate change manifested in elevated temperatures. Therefore, we may presume that as long as human influence in higher altitudes does not decrease, the spread of alien species to higher altitudes will continue. On the contrary, Medvecká et al. (2014) describe a general decrease in the relative richness and total cover of archaeophytes and neophytes with increasing altitude in the invaded habitats. This is especially the case for archaeophytes that are predominantly of Mediterranean and Sub-Mediterranean origin. Distribution of archaeophytes is associated also with their ecological demands for environmental conditions - in lowlands we can find termophilous species prefering conditions of fertile and basic soils (e. g. *Sinapis arvensis, Hyoscyamus niger, Portulaca oleracea*), on the contrary species tolerating cold, acid and poor soils occur in higher altitudes (e. g. *Spergula arvensis*).

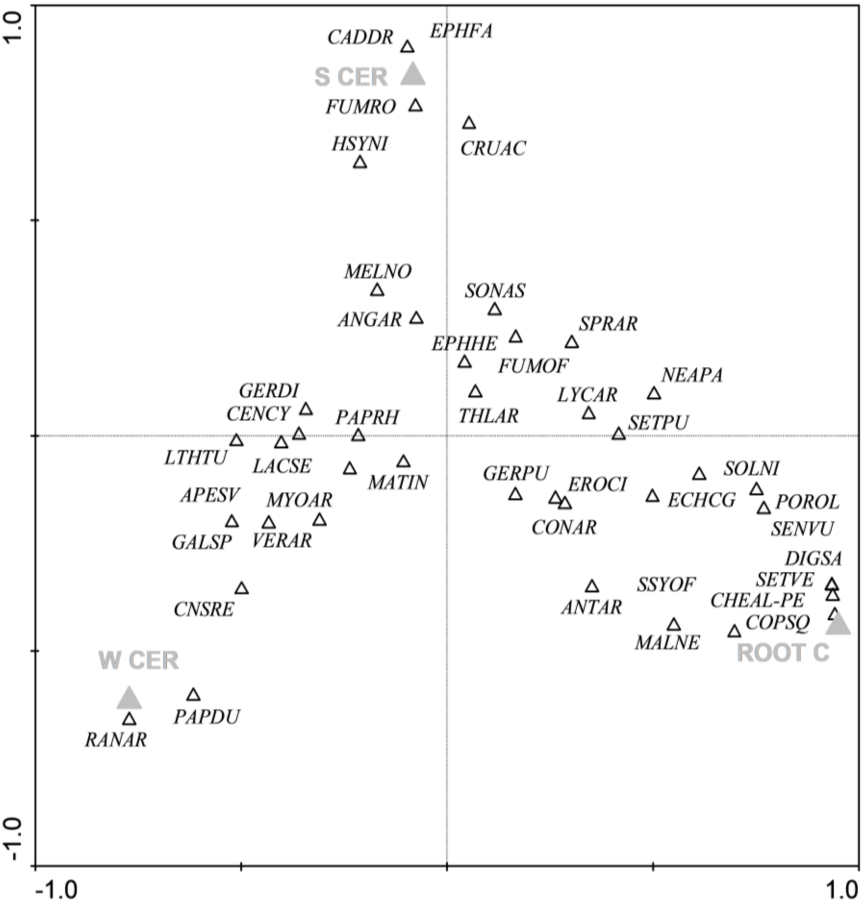

Figure 4. Ordination diagram, *pCCA*. Occurrence of archaeophytes in different crops. Minimum species fit 2% – 42 species from 88.

Abbreviations: W CER – winter cereals; S CER – spring cereals; ROOT C – wide-row crops; ANGAR – *Anagallis arvensis*; ANTAR – *Anthemis arvensis*; APESV – *Apera spica-venti*; CADDR – *Cardaria draba*; CENCY – *Centaurea cyanus*; CHEAL-PE – *Chenopodium pedunculare*; CNSRE – *Consolida regalis*; CONAR – *Convolvulus arvensis*; COPSQ – *Coronopus squamatus*; CRUAC – *Carduus acanthoides*; DIGSA – *Digitaria sanguinalis*; ECHCG – *Echinochloa crus-galli*; EPHFA – *Euphorbia falcata*; EPHHE – *Euphorbia helioscopia*; EROCI – *Erodium cicutarium*; FUMOF – *Fumaria officinalis*; FUMRO – *Fumaria rostellata*; GALSP – *Galium spurium*; GERDI – *Geranium dissectum*; GERPU – *Geranium pusillum*; HSYNI – *Hyoscyamus niger*; LACSE – *Lactuca serriola*; LTHTU – *Lathyrus tuberosus*; LYCAR – *Lycopsis arvensis*; MALNE – *Malva neglecta*; MATIN – *Tripleurospermum inodorum*; MELNO – *Silene noctiflora*; MYOAR – *Myosotis arvensis*; NEAPA – *Neslia paniculata*; PAPDU – *Papaver dubium*; PAPRH – *Papaver rhoeas*; POROL – *Portulaca oleracea*; RANAR – *Ranunculus arvensis*; SENVU – *Senecio vulgaris*; SETPU – *Setaria pumila*; SETVE – *Setaria verticillata*; SOLNI – *Solanum nigrum*; SONAS – *Sonchus asper*; SPRAR – *Spergula arvensis*; SSYOF – *Sisymbrium officinale*; THLAR – *Thlaspi arvense*; VERAR – *Veronica arvensis.*

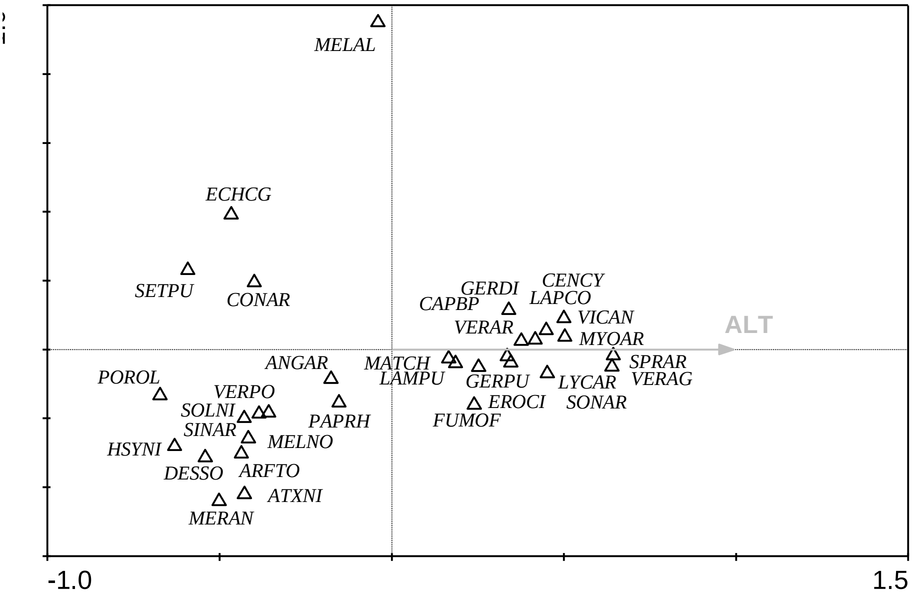

Figure 5. Ordination diagram, *pCCA*. Occurrence of archaeophytes at different altitudes. Minimum species fit 3% – 32 species from 88.

Abbreviations: ALT – altitude; ANGAR – *Anagallis arvensis*; ARFTO – *Arctium tomentosum*; ATXNI – *Atriplex sagittata*; CAPBP – *Capsella bursa-pastoris*; CENCY – *Centaurea cyanus*; CONAR – *Convolvulus arvensis*; DESSO – *Descurainia sophia*; ECHCG – *Echinochloa crus-galli*; EROCI – *Erodium cicutarium*; FUMOF – *Fumaria officinalis*; GERDI – *Geranium dissectum*; GERPU – *Geranium pusillum*; HSYNI – *Hyoscyamus niger*; LAMPU – *Lamium purpureum*; LAPCO – *Lapsana communis*; LYCAR – *Lycopsis arvensis*; MATCH – *Matricaria recutita*; MELAL – *Silene latifolia* subsp. *alba*; MELNO – *Silene noctiflora*; MERAN – *Mercurialis annua*; MYOAR – *Myosotis arvensis*; PAPRH – *Papaver rhoeas*; POROL – *Portulaca oleracea*; SETPU – *Setaria pumila*; SINAR – *Sinapis arvensis*; SOLNI – *Solanum nigrum*; SONAR – *Sonchus arvensis*; SPRAR – *Spergula arvensis*; VERAG – *Veronica agrestis*; VERAR – *Veronica arvensis*; VERPO – *Veronica polita*; VICAN – *Vicia angustifolia*.

CONCLUSION

On arable land, almost half of all weed species are archaeophytes. The most abundant species include *Fallopia convolvulus*, *Cirsium arvense*, *Tripleurospermum inodorum*, *Capsella bursa-pastoris*, *Thlaspi arvense* and *Convolvulus arvensis*. At the same time, these are harmful, economically important weeds that need to be suppressed regularly in crops.

Although the vast majority of archaeophytes (about 94%) are naturalized taxa, some species have an invasive status and spread to other habitats. In this respect, *Cirsium arvense* and *Echinochloa crus-galli* deserve particular attention. Attention should also be paid to the spread of other species such as *Conium maculatum* and *Portulaca oleracea*. The recommended strategy for these species is a stratified approach balancing between the local needs and the available resources for eradication

From the point of view of the monitored factors, the majority of the variation was explained by altitude. Unlike the neophytes, archaeophytes also appear in the higher arable land of the Czech Republic. The highest occurrence of archaeophytes was found in cereals, especially in spring ones. Many archaeophytes, however, occur more in wide row crops. A higher presence of archaeophytes was proved in organically managed areas. Nevertheless, *Bromus sterilis* is associated with conventionally cultivated areas.

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