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PRELIMINARY DATA ABOUT THE INVASIVE ABILITY OF *Solidago canadensis* L. AND ITS ESTABLISHMENT IN CROPS IN OUR COUNTRY

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Abstract

The two species of Solidago, S. canadensis and S. gigantea, which were introduced in our country, as well as other parts of Europe, as ornamental plants, have become invasive in natural areas and, more recently, in crops. Several physical, biochemical, or biological characteristics support its ability to intrude into natural environments and crops. The vigorous monopodial growth of the stem until the inflorescence is induced enables species to attain a height of 2 meters, supported by extensive sclerenchyma rows found within the stem's internal structure. Using our observations and available S. canadensis occurrence data from the literature, we created an updated chorology map illustrating the species distribution in Romania. Subsequently, we used the R software, with the SSDM package, to generate the potential distribution map of S. canadensis in Romania based on these data. In creating the potential distribution map of S. canadensis, we considered various environmental variables corresponding to the species' ecological preferences, such as climatic, pedological, anthropogenic factors, and water regimes. The model performed well, effectively highlighting the environmental factors influencing the species' dispersion in Romania and the areas potentially affected by the spread of S. canadensis.

Key words*: chorological map, invasive ability, Solidago canadensis L.*

INTRODUCTION

The project's final report on the Adequate Management of Invasive Alien Species (IAS) in Romania lists *Solidago canadensis* L. among the 94 IAS of concern for the country. During the project's three years of field studies, *S. Canadensis* - a species introduced deliberately for ornamental purposes, as well as its congeneric *S. gigantea* - was reported regularly. In the last year (2023), the species was represented in 1.35% of all records (Anastasiu et al., 2023).

According to the updated list of non-native ornamental plants in Romania, *S. canadensis* is included among the 16 species with significant impacts, as per the EASIN (European Alien Species Information Network) Catalogue. As an established invasive alien plant, it receives a rating of 5 on the scale of occurrence in our country, where 1 represents the presence of an IAS species in a single locale, 5 in 101 to 500 locales, and 7 in more than a thousand locales. The first mention of its presence in our country dates back to 1866. Individuals and populations of *S. canadensis* can now be found in either natural, semi-natural, or artificial environments (Urziceanu et al., 2020).

Several scientific papers have highlighted the presence of *S. canadensis* in different habitats in our country. It thrives best on disturbed or uncultivated soils, along roads and railways, through railway stations, near places where plant debris from gardens is stored, and next to fences (Anastasiu et al., 2019), but it can also be found in crops. Discussions about the presence of this species in different crops in our country are scarce.

The mention of *S. canadensis* as a neophyte species in natural grasslands, meadows, and pastures belonging to the *Potentillo-Polygonetalia* and *Arrhenatheretalia* orders

was made in a paper by Sîrbu et al. in 2016. They highlight that the capacity of *Solidago* plants to release various allelopathic compounds into the soil that disrupt the normal development of native grassland species makes it a particularly harmful weed and a formidable competitor in natural environments.

A study on alien plants from Dâmbovița County describes *S. canadensis* as a species with populations of over 100 individuals per square meter in some locations, some considered hotspots. It is still cultivated as a decorative plant in private gardens but can be found in cemeteries, vacant lands, or natural habitats. Different disturbances caused by human activities account for the species' presence in natural environments. However, the species is not listed among crop weeds (Neblea & Marian, 2022).

Particular attention is given to the presence of the *Solidago* invasive species in protected areas. Although species populations were not reported in the Danube Delta Biosphere Reserve, the authors point out that they exist in other regions and countries (Anastasiu et al., 2014).

Research conducted in the Nature 2000 sites in the Oltenia regions revealed populations of *Solidago canadensis* L. in the azonal forests of *Fraxinus excelsior* L. and *Alnus* species (91E0* habitat) located in the alluvial plain of the Danube and along the lower courses of large streams and rivers. The same applies to the second azonal forest type, with *Salix alba* L., *S. fragilis* L., and *Populus alba* L. (92A0 habitat) (Răduțoiu et al., 2023).

In addition to the competition with natural or crop species, *Solidago* plants pose a significant threat to efforts for a low-input form of agriculture. Szabó et al. (2022) demonstrate that the association of *Solidago* plants with aphids, which are vector viruses that cause harm to crop plants such as potatoes, alfalfa, or maize, necessitates the implementation of a novel weed control protocol for crops grown under low-input conditions. This protocol could reduce the adverse effects of aphid-infesting goldenrods and keep these spaces environmentally friendly, as are the EU suggestions (https://www.euronews.com/green/2024/02/23/agroecology-is-the-only-way-forward).

Furthermore, it is imperative to reassess the prevalent perception regarding the absence of any management measures, specifically weed management, within protected areas (Szabó et al., 2022).

The paper discusses the actual state of *Solidago canadensis* L. in our country, correlated with invasive features that favour its establishment and spread. Furthermore, it analyzes the potential presence of the species at the country level and on arable land.

MATERIALS AND METHODS

Free-hand sections obtained from aerial vegetative organs (stem and leaves) were analyzed and photographed on a light microscope (Leica DM1000 LED microscope, equipped with a Leica DFC295 video camera) to illustrate the internal structure and their role in the suitability of species in their habitats. Plant material was collected from the Botanical Garden "Ioan Todor" of University of Agronomic Sciences and Veterinary Medicine of Bucharest at the end of October 2023.

To illustrate the actual presence of *Solidago canadensis* L. in various crops, the authors utilized field data gathered from observations, which were incorporated into maps released by the Management of Invasive Alien Plants Project. Furthermore, detailed investigations into various crops in the Fagaras Land area were added. Subsequently, we used the R software, with the SSDM (Stacked Species Distribution Modelling) package, to generate the potential distribution map of *S. canadensis* in Romania based on these data. In creating the potential distribution map of *S. canadensis*, we considered various environmental variables corresponding to the species' ecological preferences, such as climatic, pedological, anthropogenic factors, and water regimes.

RESULTS AND DISCUSSIONS

The causes of the current establishment and spread of plants

Solidago canadensis L. originated in North America. Panțu (1929) refers to the species in the list of plants known by Romanian people as an ornamental plant cultivated in gardens. The Flora of Romania, Tom IX (1964), highlights

that escaped plants from gardens have multiplied independently and, possibly, established a second range throughout Europe and our country.

In the first map (Figure 1), the actual occurrence of *Solidago* populations is compared to their potential presence.

The ecological requirements, as outlined by Sârbu et al. (2013), indicate that *S. canadensis* is a heliophyte, eurythermal, and xero-mesophyte that thrives in soils that have been enriched with nitrogen.

A study of the Arieş River Valley shows that the river and riparian zone facilitate the migration of invasive alien species and help them establish themselves on neighboring grasslands or agricultural fields (Onete et al., 2015). This may also be a plausible scenario for the populations of *S. canadensis*, as our results indicate that the majority of their current occurrences (736 out of 850 occurrences) are located within 100 meters of rivers.

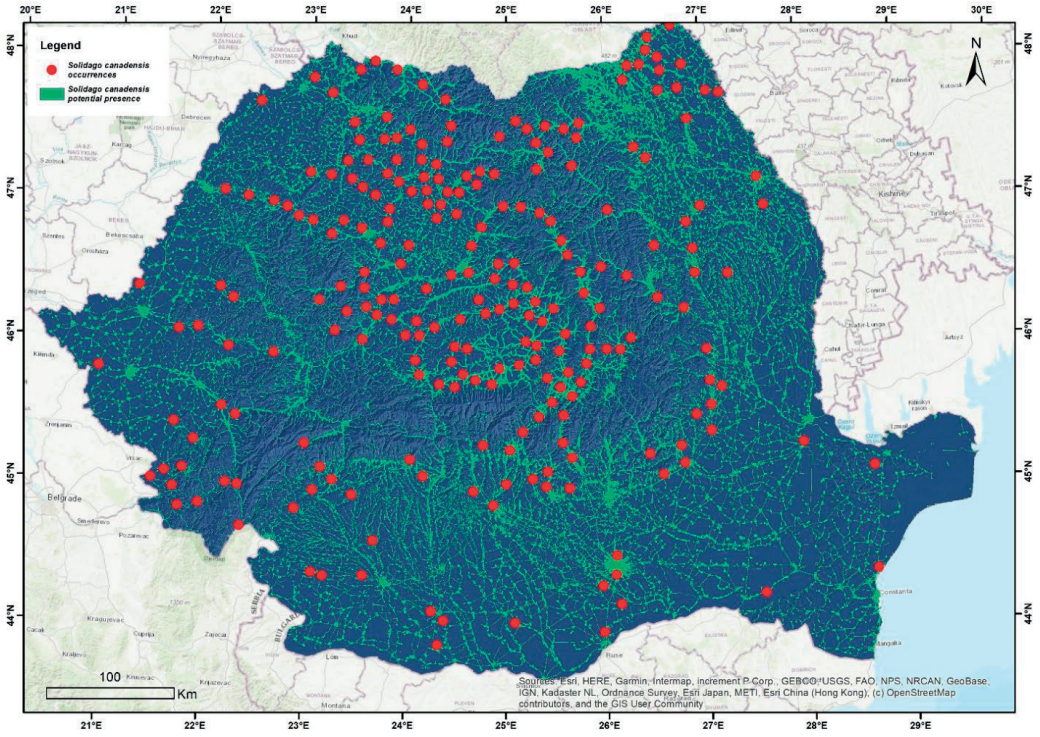

Figure 1. The map of the actual and potential presence of *Solidago canadensis* L. in Romania

The success of population establishment and spread is based on the individuals' morphological, anatomical, biological, and biochemical traits and on the genetic variability of the whole population.

S. canadensis is a perennial hemicryptophyte that forms a cylindrical and prostrate rhizome in the soil, with stolons that can reach 1 meter long. The below-ground parts of plants play a double role as storage and vegetative propagation organs, and that represents one of the principal difficulties in eradicating individuals (Wang et al., 2022). In the soil, at the rhizosphere level, there can also be mutualistic relationships constructed with particular microbes that help *Solidago* plants overcome other species in their habitat (Sun & He, 2010). The presence of *Solidago* plants affects some soil properties, such as soil moisture or magnesium content, while other properties remain unchanged (Baranova et al., 2017).

The release of allelopathic compounds from introduced plant species can have a negative impact on native plants from Europe due to the

absence of co-evolution, and it is one of the reasons for the successful establishment of non-native plants (Abhilasha et al., 2008). Many studies were conducted regarding the allelopathic effects of *Solidago* plants on other species' germination. Specifically, experiments demonstrated the inhibitory effect of various extracts from *S. canadensis* plants on the germination and growth of seeds of *Arabidopsis* (Abhilasha et al., 2008), rapeseed, ryegrass (Baležentienė, 2015), *Lactuca sativa* L., or *Lepidium sativum* L. (Judžentiene et al., 2023). However, the soil's biochemistry and relationships with microbes can alter the allelopathic effects of *Solidago* plants (Abhilasha et al., 2008).

The aerial parts of plants have morphological and structural characteristics that support the individual species' competitiveness in new habitats.

The aerial stems can reach 2 meters high and grow monopodially until below the inflorescence (Figure 2). *S. canadensis*'s stem is short, patent, and densely haired along its entire length.

Figure 2. The aerial parts of *Solidago canadensis* L.

The secondary internal structure provides strong support to the plant's upper part, which consists of many curved branches of a panicle with anthodium through extensive sclerenchyma rows and a well-developed xylem (Figure 3).

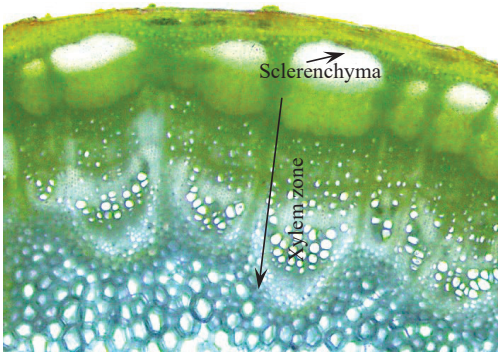

Figure 3. The xylem and sclerenchyma in the secondary structure of the stem

Many narrow leaves are arranged from the base to the top of the stem. They are hairy on both sides or only on the abaxial side. Two rows of palisade cells can be observed under the internal lamina structure's upper epidermis, enhancing photosynthesis (Figure 4).

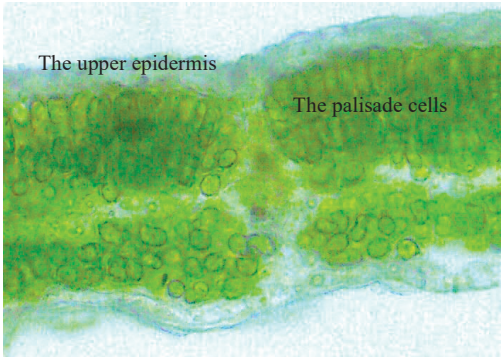

Figure 4. The palisade cells in the internal structure of the lamina

Stomata, which are located in the lower epidermis (hypostomatous leaf) to avoid water evaporation, are composed of two guard cells accompanied by two subsidiary cells with longitudinal axes parallel to those of the guard cells (paracytic type) (Figure 5).

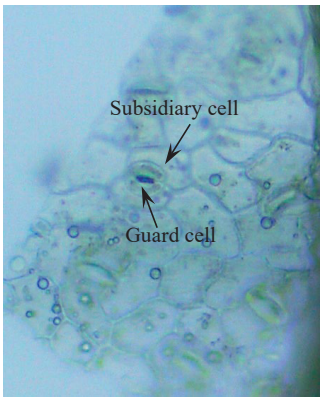

Figure 5. Paracytic type of stomata

The structural features of *S. canadensis*' lamina are discussed in different papers. In Dobjanski et al. (2021), the lamina is described as having an equifacial structure, and Wang et al. (2022) describe it as having a single palisade cell layer. Do environmental adaptations cause these differences? We subscribe to the affirmations of Wang et al. (2022) that supplementary morphological and anatomical studies are necessary in correlation with environmental factors. Likewise, according to Tian et al. 2023, three levels of ploidy in native and introduced habitats, namely diploid 2n = 18, tetraploid 2n = 36, and hexaploid 2n = 54, enhanced the success of. *S. canadensis* populations in invasion and distinguished them based on morphological (and possibly structural) traits.

Potential presence and expansion of Solidago canadensis populations on agricultural land in our country

The potential for the future expansion of *Solidago* populations hinges on their ability to adapt to contemporary habitats. Being a successful invader, *S. canadensis* also excels at responding to environmental changes.

In a study published in 2023, Tian et al. noted that polyploid populations exhibit a greater distribution area in regions with higher mean temperatures in July, both in Europe and Asia than their diploid counterparts. These findings suggest the possibility of polyploid populations adapting to temperature fluctuations and future temperature rises.

Figure 6 reproduces a model of an eventual expansion of *S. canadensis* populations in Romania.

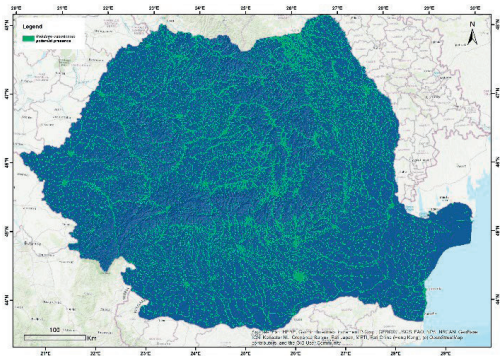

Figure 6. *Solidago canadensis* L. wide-ranging potential presence in Romania

The model was mainly influenced by proximity to roads (65.78%), which may suggest that road accessibility or disturbances related to roads might play a significant role in the distribution and expansion patterns of these populations.

It should be noted that *S. canadensis* populations have the capacity to hybridize with native European species, such as *Solidago virgaurea* L., and form a new threatening hybrid (*S.* × *niederederi* Khek) for the native *S. virgaurea* population complex (Skokanová et al., 2020).

Specific management actions on arable lands stimulate the expansion of *S. canadensis* populations in crops, besides the favorability of the agricultural lands.

S. canadensis, being a perennial species with a vegetative multiplying capacity, is capable of easily dispersing through clonal fragments. An experiment conducted on the entire rhizome and cuttings demonstrated that despite the vegetative parts' burial depth, the individuals sprouted and re-established themselves (Rosef et al., 2019). The authors also consider the possibility of seeds being spread by the wind from the road edges to the surrounding areas when vehicles traverse the adjacent roads.

Figure 7 reproduces a possible expansion of *S. canadensis* on the arable lands in our country.

According to our analysis, 27.7% of the potential distribution of *Solidago canadensis* L., equivalent to 7582 hectares, falls within areas of arable land that the species could potentially invade.

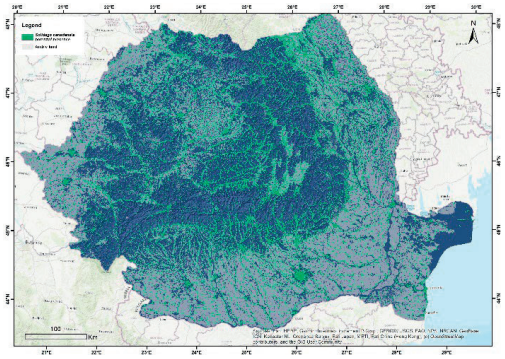

Figure 7. *Solidago canadensis* L. wide-ranging potential presence on arable lands of Romania

The relief of the Land of Fagaras territory is represented by a layered alluvial-proluvial plain, formed by the terraces and meadows extended along the Olt valley and its tributaries (Ghinea, 1996).

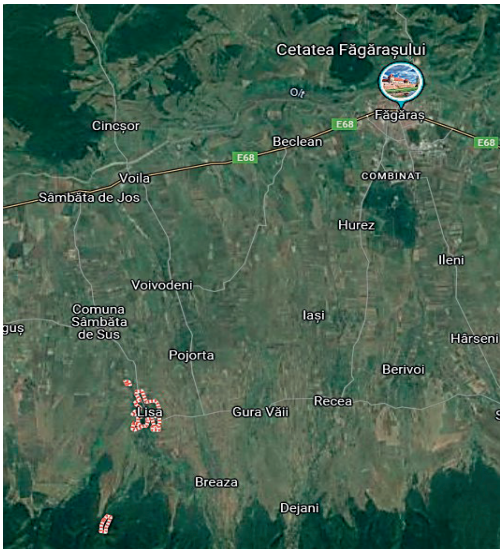

Figure 8. The area of investigation in the Land of Fagars (https://www.google.com/maps/)

In this area (Figure 8), large populations of *Solidago* have been found on arable lands. We illustrate with an example taken around Lisa village, Brasov County. The low fieldwork input applied to certain crops (soybean, maize) and favorable soil conditions were the reasons for the massive settlement of *S. canadensis* populations in these crops (Figure 9).

Figure 9. *Solidago canadensis* L. in soybean crop near Lisa village

CONCLUSIONS

Solidago canadensis L., originally cultivated as an ornamental species, has become an alien invasive species in Europe and in our country due to its morphological, structural, and biological features.

Three levels of ploidy, observed in native and alien populations, significantly enhanced the invasive capacity of *Solidago* populations.

The three maps showed the actual and possible expansion of *S. canadensis* in our country, both in their natural environments and on cultivable land.

Several factors contribute to the spread of this species, such as crop and weed management.

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