DOI: 10.1111/epp.13048

PM 9/32 (1) *Solanum carolinense*

Specific scope: This Standard describes the control procedures aiming to monitor, contain, and eradicate *Solanum carolinense*.
Specific approval and amendment: First approved in 2024–09.

1 | INTRODUCTION

Solanum carolinense (Solanaceae) is a perennial herb native to North America (Wahlert et al., 2015). The species has several weedy attributes (e.g., reproduces vegetatively, rapid growth, prolific seed production, grows in a variety of biotic and abiotic conditions) (Bassett & Munro, 1986). The species was introduced into the EPPO region most likely in the middle of the 20th century.

Solanum carolinense is regarded to be a major agricultural problem. It is a common weed in many crops and pastures and affects crop yield and quality (Follak, 2020; Van Wychen, 2020), it is considered toxic to livestock (Bassett & Munro, 1986) and a host to many crop diseases and pests (Wahlert et al., 2015).

In the EPPO region, *S. carolinense* occurs in different habitats including banks of major rivers (e.g. the Waal; Dirkse et al., 2007), ruderal habitats (e.g. roadsides, port areas; Pérez et al., 2020), pastures and crop fields (Follak, 2020; Klingenhagen et al., 2012). The spread of *S. carolinense* is largely driven by human activities. Propagules of *S. carolinense* can be spread by agricultural machinery with contaminated soil attached both within fields and from field-to-field. Additionally, management and/or construction works in habitats that act as corridors for spread (e.g. roadsides) may facilitate the spread of the species (Follak, 2020; Wehtje et al., 1987). The establishment of *S. carolinense* by root fragments is assumed to be very successful, as the species can grow vegetatively from very small fragments (Ilnicki & Fertig, 1962; Miyazaki, 2008).

In 2022, *S. carolinense* was added to the EPPO A2 List of pests recommended for regulation as quarantine pests (EPPO, 2022a). The species is regulated by a number of EPPO countries (EPPO, 2022b), such as Azerbaijan, Kazakhstan, Jordan, Russia, Ukraine and Uzbekistan (all A1 List) as well as in Belarus and Israel (Quarantine pest) and Georgia (A2 List).

Further information on the biology, distribution and economic importance of *Solanum carolinense* can be found in Wahlert et al. (2015) and EPPO (2022b).

EPPO member countries at risk are advised to prepare monitoring activities and a contingency plan for the eradication and containment of this pest.

This Standard presents the basis of a national regulatory control system for the monitoring, eradication, and containment of *S. carolinense* and describes:

- Elements of the monitoring programme that should be conducted to detect a new infestation or to delimit an infested area;
- Measures aiming to eradicate recently detected populations (including an incursion);
- Containment measures: to prevent further spread in a country or to neighbouring countries, in areas where the pest is present and eradication is no longer considered feasible.

Regional cooperation is important, and it is recommended that countries should communicate with their neighbours to exchange views on the best programme to implement, in order to achieve the regional goal of preventing further spread of the pest.

For the efficient implementation of monitoring and control at a national level, cooperation between the relevant public bodies (e.g. NPPOs, Ministries of Environment, Ministries in charge of transport, water management), as well as with other interested bodies (associations) should be established.

2 | MONITORING OF *SOLANUM CAROLINENSE*

Staff of organizations in charge of the monitoring of the species should be trained to recognize the plant at all stages in its lifecycle, even when present as small populations. This may include staff of NPPOs, botanists, agronomists, farmers, nature conservation managers, municipal authorities and road and rail maintenance workers. As this plant has the potential to grow in a range of habitats, citizen science projects may be implemented to encourage landholders and other citizens to report sightings of *S. carolinense*.

Regular surveys (see ISPM 6: *Surveillance*; FAO, 2018) are necessary to determine the geographical distribution of the plant and its prevalence. Monitoring can concentrate on areas that are climatically suitable and most vulnerable to colonization. It should be carried out in likely places of introduction of *S. carolinense*, such as disturbed habitat complexes and arable land. High risk places of introduction include, summer crops, such as maize and soybean and surroundings of grain and fodder warehouses, oil mills, grain processing factories and fodder industry factories where potentially contaminated plant material is stored or processed.

3 | ERADICATION OF *SOLANUM CAROLINENSE*

Any eradication programme for *S. carolinense* in the case of recently detected populations is based on the delimitation of the infested area within the country and the application of measures to both eradicate and prevent further spread of the pest. The feasibility of eradication depends on the size and designation of the infested area, the density of the population and the accumulated seed bank, and accessibility of the site. Eradication may only be feasible in the initial stages of infestation.

Measures are described in Appendix 1.

4 | CONTAINMENT OF *SOLANUM CAROLINENSE*

The containment programme for *S. carolinense* in the case of established populations is based on the application of measures to prevent further spread of the species in country or between neighbouring countries.

Measures are described in Appendix 2.

5 | COMMUNICATION AND COLLABORATION

Regional cooperation is essential to promote phytosanitary measures and information exchange in identification and management methods. NPPOs can provide land managers and stakeholders with identification guides and facilitate regional cooperation including information on site-specific studies of the plant, control techniques and management. Professionals (e.g. administration, foresters) should be informed about the threat to natural and managed land, and about preventive measures. Integrated management, involving different sorts of land managers and various management measures will be more effective and efficient.

ACKNOWLEDGEMENTS

This Standard was first drafted by Mr. S Follak (AT) and Ms. D Marisavljevic (RS). It was reviewed by the EPPO Panel on Invasive Alien Plants.

REFERENCES

Armel GR, Wilson HP, Richardson RJ, Hines TE (2003) Mesotrione combinations for postemergence control of horsenettle (*Solanum carolinense*) in corn (*Zea mays*). *Weed Technology* 17, 65–72.

Banks PA, Kirby MA, Santelmann PW (1977) Influence of postemergence and subsurface layered herbicides on horsenettle and peanuts. *Weed Science* 25, 5–8.

Bassett IJ, Munro DB (1986) The biology of Canadian weeds 78. *Solanum carolinense* L. and *Solanum rostratum* Dunal. *Canadian Journal of Plant Science* 66, 977–991.

Beeler JE, Rhodes GN, Bates GE, Main CL, Mueller TC (2004) Horsenettle (*Solanum carolinense*) control in tall fescue (*Festuca arundinacea*) and clover (*Trifolium* spp.) pastures with mixtures of 2,4-D and picloram. *Weed Technology* 18, 1091–1095

Dirkse GM, Holverda WJ, Hochstenbach SMH, Reijerse AI (2007) *Solanum carolinense* L. en *Pimpinella peregrina* L. in Nederland. *Gorteria* 33, 21–27.

Enloe SF, Tredaway Ducar J, Dorough HD (2010) Weed control with aminocyclopyrachlor in Alabama pastures. Page 162 in Proceedings of the 63rd Southern Weed Science Society Meeting. Little Rock, AR: Southern Weed Science Society [Abstract].

Elmore CD, Wesley R, Cooke F, Hurst H (1984) Effects of tillage and irrigation on weeds in a wheat-soybean double-cropping system. Proceedings, Southern Weed Science Society, 37th annual meeting, p. 316.

EPPO (2022a) A2 List of pests recommended for regulation as quarantine pests, https://www.eppo.int/ACTIVITIES/plant_quarantine/A2_list [accessed on 12 October 2022].

EPPO (2022b) EPPO Technical Document No. 1086. Pest risk analysis for *Solanum carolinense*. EPPO, Paris. Available at https://gd.eppo.int/taxon/SOLCA/documents [accessed on 12 October 2022].

FAO (2017) *ISPM 41 International movement of used vehicles, machinery and equipment*. FAO, Rome.

FAO (2018) *ISPM 6 Surveillance*. FAO, Rome.

Follak S (2020) Distribution and small-scale spread of the invasive weed *Solanum carolinense* in Austria. *EPPO Bulletin* 50, 322–326.

Fried G (2021) Fiche de reconnaissance Morelle de la Caroline ANSES-LSV Unité d'entomologie et plantes invasives. https://draaf.bretagne.agriculture.gouv.fr/IMG/pdf/FR_Solanum_carolinense_0921_cle073468.pdf.

Greene WC, Hagood S, Tracy B, Abaye O, Flessner ML (2022) Broadleaf weed control and white clover response to florpyrauxifen-benzyl + 2,4-D and common pasture herbicides. *Weed Technology* 36, 708–715, doi: 10.1017/wet.2022.67.

Ilnicki RD, Fertig SN (1962) Life History Studies as Related to Weed Control in the Northeast. 3. Horse Nettle. Bulletin 368. Kingston: University of Rhode Island, Agricultural Experiment Station.

Klingenhagen G, Wirth M, Wiesmann B, Ahaus H (2012) Occurrence of horse nettle (*Solanum carolinense* L.) in North Rhine-Westphalia. *Julius-Kühn-Archiv* 434, 601–604, DOI: 10.5073/jka.2012.434.077.

Miyazaki K (2008) Root system architecture and its relationship to the vegetative reproduction function in horsenettle (*Solanum carolinense*). *Weed Biology and Management* 8, 97–103

Nichols RL, Cardina J, Powell Gaines T (1991) Growth, reproduction and chemical composition of horsenettle (*Solanum carolinense*). *Weed Technology* 5, 513–520.

Norsworthy JK (2008) Effect of tillage intensity and herbicide programs on changes in weed species density and composition in the southeastern coastal plains of the United States. *Crop Protection* 27, 151–160.
Pérez JJP, Pando FJS, Pérez RP (2020) Cuatro solanáceas (Solanaceae) alóctonas nuevas para la flora de Galicia. *Nova Acta Científica Compostelana (Bioloxía)* 27, 61–68.
Phillips WP, Israel TD, Mueller TC, Armel GR, West DR, Green JD, Rhodes, Jr. GN (2016) Utility of aminocyclopyrachlor for control of horsenettle (*Solanum carolinense*) and tall ironweed (*Vernonia gigantea*) in cool-season grass pastures. *Weed Technology* 30, 472–477.
Prostko, EP, Ingerson Mahar J, Majek BA (1994) Postemergence horsenettle control in field corn. *Weed Technology* 8, 441–444.
Van Wychen L (2020) 2020 Survey of the Most Common and Troublesome Weeds in Grass Crops, Pasture and Turf in the United States and Canada. Weed Science Society of America National Weed Survey Dataset. Available: http://wssa.net/wp-content/uploads/2020-Weed-Survey_Grass-crops.xlsx [accessed 26 July 2022].
Vangessel MJ (1999) Control of perennial weed species as seedlings with soil-applied herbicides. *Weed Technology* 13, 425–428.
Wahlert GA, Chiarini FE, Bohs L (2015) A revision of *Solanum* section *Lathyrocarpum* (the Carolinense clade, Solanaceae). *Systematic Botany* 40, 853–887. https://doi.org/10.1600/036364415X689302.
Wehtje G, Wilcut JW, Hicks TV, Sims GR (1987) Reproductive biology and control of *Solanum dimidiatum* and *Solanum carolinense*. *Weed Science* 35, 356–359.
Whaley CM, Vangessel MJ (2002) Horsenettle (*Solanum carolinense*) control with a field corn (*Zea mays*) weed management program. *Weed Technology* 16, 293–300.

APPENDIX 1 - ERADICATION PROGRAMME

The national regulatory control system involves four main activities:

1. Surveillance to fully investigate the distribution of the pest,
2. Containment measures to prevent the spread of the pest,
3. Treatment and/or control measures to eradicate the pest when it is found,
4. Verification of pest eradication.

Additional supporting mechanisms can be established by the responsible authority (i.e., border control or restrictions on the movement of used machinery).

Eradication depends on effective surveillance to determine the distribution of the pest and containment to prevent spread while eradication is in progress. Any eradication measures should be verified by surveillance to establish if attempts and measures have been successful. Staff in charge of the control of the plants should avoid touching the plant with bare skin (due to its prickles).

1. Surveillance

A delimitation survey should be conducted to determine the extent of the distribution of *S. carolinense*. Particular attention should be given to areas adjacent to infested sites that might receive root fragments by human-assisted spread (ruderal sites, roadsides, crop fields) (Figure A1). Its presence is mostly related to habitats with human disturbance. Surveillance should also be increased in areas of the EPPO countries where *S. carolinense* invasion is in the phase of increased spread and establishment (e.g. Austria and Italy).

2. Containment measures

NPPOs should provide land managers, farmers, stakeholders with identification guides including information on preventive measures and control techniques (see for example Fried, 2021). Unintentional transport of seeds and root fragments through the transfer of contaminated soil material, grain (animal feed), and by vehicles and machinery should be avoided. Movement of soil from infested areas should be prohibited. Equipment and machinery should be cleaned to remove soil before moving to an uninfested area (see ISPM 41: *International movement of used vehicles, machinery and equipment*; FAO, 2017).

3. Treatment and control

It is technically possible to achieve eradication of *S. carolinense* by a combination of chemical and mechanical means; however, it is most applicable only to small infestations (not well established) and outbreaks. Established populations are considered very difficult to eradicate, because of the species' extensive root system and high capacity of regeneration from small root fragments.

Herbicides and mechanical control options applied to individual plants or patches (spot treatment) may allow effective control of the species (see Appendix 2).

FIGURE A1 Regular monitoring in high-risk areas is important to detect early infestations of *Solanum carolinense* (shown in the red circle). The infestation occurs mostly from the edge of the field.

4. Verification of pest eradication

Measures should be conducted until no emergence or sprouting of *S. carolinense* is found. Treated sites need to be monitored until at least five years after the last signs of sprouting or germination, to ensure eradication was achieved.

APPENDIX 2 - CONTAINMENT PROGRAMME

In case of established and large populations in agricultural areas and non-crop areas, eradication is difficult to achieve. Control measures will be determined depending on the situation in different habitats, climates, levels of infestation and legal requirements in the countries. In crops, a more diverse combination of herbicide sites of action, crop rotation and tillage practices will help to reduce population size.

1. Surveillance

A delimitation survey should be conducted to determine the extent of the distribution of *S. carolinense*. (see Appendix 1).

2. Containment measures

Containment measures regarding the prevention of the spread through the movement of soil, machinery or any contaminated commodity such as grain (animal feed) should be applied (see Appendix 1).

3. Treatment and control

Control of *S. carolinense* requires integrated management with a combination of cultural, mechanical and chemical methods. Its control is achieved by suppressing shoot emergence from the root system. Complete control of *S. carolinense* cannot be achieved with a single herbicide application. Long-term control is possible if applications are made at the right time and repeated over several years.

Chemical control

It should be highlighted that the availability of products containing active ingredients will vary nationally and other products may be available and effective. Indications of the approved uses for each active ingredient may be incomplete. Products should be used following the instructions on the label and in line with the relevant plant protection product regulations.

In general, *S. carolinense* is moderately susceptible to herbicides and multiple applications and/or tank mixtures are required for adequate control (Table A1). However, only a few studies have evaluated herbicides and herbicide combinations for *S. carolinense* control and most of these were done in North America and refer mainly to maize (e.g. Armel et al., 2003; Prostko et al., 1994; Whaley & Vangessel, 2002). In maize, effective active ingredients (in combination) are from the group of synthetic auxins, triketones and sulfonylureas. Whaley and Vangessel (2002) showed that an autumn glyphosate application followed by post emergence herbicides can be a useful tool for farmers in reducing *S. carolinense* shoot densities. For other major and minor crops (e.g. soybean, oil pumpkin, vegetables) limited to no information on herbicide efficacy is available.

Vangessel (1999) tested several pre-emergence herbicides for control of *S. carolinense* emerging from seeds in a greenhouse study. Metribuzin provided 96% control (0.28 kg/ha), while values for control using pendimethalin and metolachlor were <30%.

In pastures, studies reported acceptable levels of *S. carolinense* control depending on application timings (e.g. Beeler et al., 2004; Enloe et al., 2010; Phillips et al., 2016; Table A1). Treatments need to be repeated for 2 or 3 years. Strategies include selective control of *S. carolinense* with a single application. Picloram +2,4-D controlled *S. carolinense* 81%–99% in the season of treatment, but control was only 47%–66% in the following year (Beeler et al., 2004). Control was >95% when the species was treated at heights 10–15 cm and 15–25 cm. Enloe et al. (2010) reported that aminopyralid +2,4-D controlled *S. carolinense* >90% in the season of treatment. Aminopyralid+2,4-D, 2,4-D+dicamba, triclopyr +2,4-D resulted in *S. carolinense* control >75% in mixed stands of cool-season grasses and legumes 90 days after treatment (Greene et al., 2022).

Glyphosate treatments showed increasing control as the plant became more mature. Excellent control was achieved when treatments (3.36 kg/ha) were made at the post-bloom or fruiting stages (Banks et al., 1977).

Mowing

Mowing can suppress vegetative growth of *S. carolinense* populations and reduce seed production (Figure A2). However, Ilnicki and Fertig (1962) demonstrated that if *S. carolinense* is mown frequently at very low height, it eventually forms a rosette growth habit, thus providing the root system with sufficient carbohydrates. Nichols et al. (1991) stated that mowing has little effect on root proliferation, but may reduce flowering and production of mature berries (Georgia/USA). Another option proposed by different extension websites (e.g. https://newswire.caes.uga.edu/story/4858/pasture-weeds.html) is the combination of repeated mowing (30-day intervals) and the treatment of the regrowth with a systemic herbicide in the autumn (Table A1, see section "pastures").

TABLE A1 Examples of herbicides to control *Solanum carolinense* in maize and pastures (post- emergence).

Herbicide(s)	Rate [g ai/ha]	Control [%][a]	Source
Maize			
Mesotrione	105	81–89	Armel et al. (2003)
Mesotrione + Primisulfuron +2,4-D	105+20+140	87–92	Armel et al. (2003)
Mesotrione +2,4-D	105+140	75–85	Armel et al. (2003)
Nicosulfuron + Dicamba	34+297	54–84	Whaley and Vangessel (2002)
Glyphosate (autumn application), Nicosulfuron + Dicamba (spring)	2200+34+297	78–91	Whaley and Vangessel (2002)
Dicamba	280	61[b]	Prostko et al. (1994)
Clopyralid	140	48[b]	Prostko et al. (1994)
Nicosulfuron	30	40[b]	Prostko et al. (1994)
Nicosulfuron + Dicamba	30+280	64[b]	Prostko et al. (1994)
Pastures			
Picloram +2,4-D	140+560 280+1120	81–99 (yr of tr) 47–66 (ff spring)	Beeler et al. (2004)
Aminopyralid	88	67	Phillips et al. (2016)
Aminopyralid +2,4-D	110+970	>90	Enloe et al. (2010)
Glyphosate	1680–4480 over 2 yr	8–10[c] (i.e. approx. 80%–100%)	Banks et al. (1977)
2,4-D+Dicamba	1065+560	81	Greene et al. (2022)
Triclopyr +2,4-D	560+1121	75	Greene et al. (2022)
Aminopyralid +2,4-D	933+115	89	Greene et al. (2022)

Note: Effectiveness depends on local conditions, density and developmental stage of *S. carolinense*. Data are from North American studies.

Abbreviations: ff, following; tr, treatment; yr, year.

[a]Visual rating (0%=no control, 100%=complete kill).

[b]Percent reduction in biomass compared to control.

[c]Visual rating (0=no control, 10=complete kill).

Cultural control

Tillage by ploughs, disks, or cultivators may increase *S. carolinense* infestations by relocating root fragments to new areas of the field or by breaking the dormancy of underground buds, resulting in new shoot growth (Ilnicki & Fertig, 1962; Wehtje et al., 1987). Where possible, ploughing should be conducted in a way to bring the majority of roots to the surface and expose them to winter freeze or desiccation. On the other hand, tillage can reduce perennial weed infestations if done frequently enough to deplete underground root reserves. Data from North America suggests that the species tends to benefit from reduced tillage to no-tillage (Elmore et al., 1984; Norsworthy, 2008). For example, Norsworthy (2008) demonstrated that perennial weed biomass – composed of *S. carolinense*, *Cyperus rotundus* L. and *Cynodon dactylon* (L.) Pers. – was nine-fold greater in no-tillage plots than in conventional tillage plots, averaged over the different herbicide programs applied (South Carolina/USA).

FIGURE A2 Mowing (cutting) can suppress vegetative growth and reduce seed production. However, *S. carolinense* quickly sprouts again.

Biological control

Biological control agents are not available.