Pueraria montana (Pueraria lobata) © *Archive of Institute Symbiosis.*

The management of kudzu vine (*Pueraria montana* var. *lobata*)

Measures and associated costs

Scientific name(s)	*Pueraria montana* var. *lobata*
Common names (in English)	Kudzu vine
Synonym	*Pueraria lobata* (Willd.) Ohwi
Authors	Melissa A. Bravo (Meadow Lake Farm Consulting Services, USA)
Reviewer	Chiara Montagnani (University of Milano-Bicocca, Italy)
Date of completion	17/09/2019
Citation	Bravo, M. A. 2019. Information on measures and related costs in relation to species included on the Union list: *Pueraria montana [Pueraria lobata].* Technical note prepared by IUCN for the European Commission.

Table of contents

Common names

BG	Кудзу
HR	penjačica kudzu
CZ	puerarie laločnatá
DA	kujibønne
NL	kudzu
EN	kudzu vine
ET	hõlmine pueraaria
FI	purppurakudzu
FR	vigne japonaise
DE	Kudzu
EL	–
HU	japán fojtóbab (kudzu)
IE	–
IT	pueraria
LV	–
LT	kalninės puerarijos skiautarėtasis varietetas
MT	–
PL	opornik łatkowaty
PT	kudzu
RO	–
SK	puerária horská laločnatá (puerária laločnatá)
SL	kudzu
ES	kuzu
SV	kudzu

Summary of the measures, emphasizing the most cost-effective options.

Pueraria species are twining, vining, semi-woody tri-lobed leaf perennial nitrogen fixing members of the legume family (Fabaceae), native to the sub-tropical ecosystems of the continent of Asia and several Pacific islands including Japan, Thailand, China, Korea, Taiwan, Indonesia, Malaysia, Papua New Guinea, Philippines, and Vietnam (van der Maesen, 1985; CABI, 2019). Some sources have reported *Pueraria* as native to Australia and Fiji, while others indicate these were early introductions exchanged between south pacific tradesmen and indigenous people, or specimens deliberately planted during military deployments by foreign powers.

By far, the most well-known intentionally introduced populations are those in the southern USA. Lesser known is that many sites in Pennsylvania date back to the introduction of kudzu as a botanical novelty at the turn of the century. Kudzu was displayed at the Centennial Exposition in Philadelphia in 1876 (Morse, 1929) and soon caught the attention of the United States Department of Agriculture (USDA) botanists (Taylor, 1929) and progressive cattlemen like Leach and Chapman (Leach, 1921), and was widely promoted and sold by mail order. The USDA sent botanists to China in the early 1900s to see the plants in their native habitat, and shipments of seedlings and root stock were imported to the USA by the millions. These were given or sold to farmers in the cotton growing regions of the south, as a soil stabilisation cover crop and nitrogen fixing forage crop (Illustrated World, 1920; Leach, 1921; Farm Journal, 1923; Morse, 1929; Taylor, 1929). Several populations in Pennsylvania surveyed from 2006-2010 were found to have been planted eighty to ninety years ago, if not earlier, as botanical novelties at the homes of members of the Philadelphia Plant Society and also for dirt and gravel road shoulder stabilisation and soil erosion control (Bravo, 2008, 2009; Bravo *et al.,* 2009; Bravo and Miller, 2010).

Numerous sources have documented kudzu introductions to North America, Central America, South America, South Africa, Oceania (Geerts *et al.,* 2016) and Europe (EPPO, 2004; CABI, 2019) over the past one hundred years. Established populations are a combination of parent and multi-aged offspring dispersed via expulsion mechanism (Bravo, 2008, 2009; Bravo *et al.,* 2009; Bravo and Miller, 2010).

Of special interest to this technical note are 32 sites recently found in Switzerland (Gigon *et al.,* 2014) and Italian localities at the border with Switzerland and scattered in several other regions of the Northern part of the peninsula (Galasso *et al.,* 2018; Montagnani *et al.,* 2018). Although kudzu has been documented as present in Europe, it is not widely established as in the USA and is not a long distance dispersed species on its own. Therefore, it is important that guidelines for prevention, surveillance, rapid eradication and management take into account the pathway of introduction and the site specifics of each spatially distinct population.

In an article in 'The Plant Press', Ashley Egan indicated that Anshan, China was the northernmost native range of *Pueraria*, whose latitude is 41.1°N (Krupnick, 2014). The latitude of all known and historical locations of established and reproducing alien kudzu populations in the United States lies south of, on, but rarely north of the 45th parallel. Occasionally, reports of ornamental plantings have flourished in areas of sub-tropical weather conditions along the Great Lakes, South Haven, Michigan (still at 42.4 degrees N), and in Ontario, Canada. This information may be useful in considering where kudzu could persist vegetatively and also set viable seed in the European Union, although in Europe the species has already colonised more Northern latitudes, such as the 47th parallel in Switzerland (C. Montagnani, pers. comm.).

The measures that provide the most cost-effective options to prevent the introduction of and to manage the genus *Pueraria*, all species and cogeners across all categories, are highlighted below.

Kudzu is a desired highly promoted edible food crop in its native range that, if left untended, is highly invasive due to its smothering fast growing vegetative biomass production. Its nitrogen fixing ability, rapid biomass accumulation and attractive pea like flowers only add to its trifecta attraction. The virtues of kudzu resound on the world wide web as often as the plant is vilified for its smothering invasive reputation. Travellers, food enthusiasts and seekers of herbal medicinal cures are encountering kudzu recipes more frequently than ever before, which has exponentially increased the likelihood of importation of viable kudzu roots, tubers and seeds, and nonviable extracts used in cosmetics.

For over a hundred years, the published literature in the USA and elsewhere (newspapers, botanical society newsletters, academic publications, scientific journals) has documented how landscape horticulture and botanical enthusiasts imported or transported kudzu beyond its established range, as demonstrated in the number of occurrences found in the USA and elsewhere outside of agriculture cropland cultivation.

To prevent the further accidental introduction of the genus *Pueraria* into the European Union, all species and cogeners have to be considered in any EDRR plan. Recent

work on several distinct populations of *Pueraria* in China (Krupnick, 2014; Egan *et al.,* 2016) supports previously published reports that there are at least 20 congeners in *Pueraria* native to temperate and sub-tropical climates of Southeast Asia. Therefore, efforts to prevent importation into the European Union should focus on all species and cogeners of the genus *Pueraria*, such as tropical kudzu, *Pueraria phaseoloides* (Heuzé *et al.,* 2017), a species often confused with and mislabelled as *Pueraria montana*.

The most likely pathway of introduction of kudzu into Europe is through the Asian edible root market. Because kudzu has rarely been found in the European Union to date, prohibiting the importation of viable *Pueraria* species and cogeners, and their root tubers, seeds and plant parts, is the most cost effective measure to ensure this genus does not become widely established as an escape from cultivation. Because the tubers of kudzu are very similar to a crop known as arrow root, this can be achieved by routinely inspecting imported tubers, seeds and plants labelled as 'arrowroot' and other 'yam like' tuber crops and 'tri-lobed legumes', as well as plants labelled as *Maranta arundicaea*, *Zamia integrifolia*, *Cassava*, araru, ararao, or hulankeeriya.

Because of the cultivation of *Pueraria* as an edible root crop in rotation with other root crops, it is highly likely that root tuber and kudzu seeds are present in cropping rotations in these regions, which is a known concern of USDA - APHIS PPQ (USDA customs, pers. comm.). As kudzu seeds are small kidney shaped and of similar size to many other small seeded legumes and root crops like turnips and spinach, another source of accidental introduction is the importation of these seeds together.

A third source of accidental introduction is in contaminated equipment or equipment parts. Given that kudzu has draped edges of crop fields in the southern United States for more than a century now, it is not surprising that seed and viable plant parts became wedged in idled equipment (junk yards). This poses a considerable risk of import by transport by contamination, for the EU to take into consideration due to internet barter/trade for farm equipment and older model automotive parts.

Prevention of secondary spread from recently introduced locations: Movement of kudzu seeds, root tubers and plant parts occurs in soil moved from one location to another by localised flooding and construction equipment. The roots of kudzu are variable in shape, but often resemble a malformed sturdy carrot with protruding 'fingers' that anchor the yam like tuber. The root crown of each root sends off lateral vegetative tendril runners that harden off after overwintering and become cork like. These *brown like a snake* ropes are of astonishing lightness and durability. As they traverse the landscape, the runners set down root knots to stabilise their expansion. Kudzu needs to climb something to flower, whether that be itself or another structure. The subsequent seed rain beneath the parent canopy becomes a source of new infestations when soil is moved by construction purposes or by heavy rains. If allowed to persist unchecked, the parent population will, after overwintering, obtain sufficient biomass to begin producing viable seeds that germinate and add to the 'density' of the patch. In Pennsylvania, where kudzu goes dormant over the winter, this maturation has been slow and viable seed was not discovered at kudzu sites until years later. But in Southern USA, where kudzu does not go dormant, seed set occurs sooner (Bravo, pers. obs.). Once the parent canopy begins to rain seed, movement of the soil beneath these canopies becomes a common secondary pathway of spread in the USA and presumably elsewhere.

Another source of secondary movement of the species is as a contaminant of used equipment, specifically farm equipment or old cars and parts that are parked in or by a kudzu site or that have been used to harvest a crop where kudzu is a weed. Kudzu seeds and kudzu root knots get lodged in the equipment and may or may not dislodge during transport. Potato and other soil crop harvesting equipment can easily dig up kudzu tubers. As such, prohibiting the movement of contaminated soil, stone and field equipment from areas known to have kudzu is an effective measure to prevent secondary spread of the species (Bravo, 2008, 2009; Bravo *et al.,* 2009, 2012a,b; Bravo and Miller, 2010).

Rare, but documented cases of kudzu seedpods and/or seeds being dispersed in tornadic winds can also transport kudzu seeds over short distances, in updrafts and downbursts from invaded locations, as observed at one locale in Pennsylvania (Bravo and Miller, 2010).

It is important to acknowledge that kudzu was legally sown in the United States as a forage crop, grazing crop and soil stabilisation cover crop since the early 1900s through the 1970s, before it was declared a noxious weed by the federal government, but no federal or state effort was made to quarantine and remove the invaded acreage. The abandonment of a once legal to sell crop created a national invasive species problem that was not addressed until the 1990s. Grazing of kudzu or forage harvesting of kudzu when seed pods are present was, for decades, a short distance pathway of species dispersal in the USA. However, other than perhaps through grazing of established populations, this is unlikely to occur in Europe, as the EU has banned the species from being planted as a forage crop.

Surveillance to discover recently introduced populations: Surveillance for new kudzu populations should be done through targeted plant surveys or inspections, and assisted by public training and participation. However, kudzu requires a long growing season to flower and some time (as long as three years, if not more in snow belt regions) to establish enough root reserve to flower. In addition, seedling kudzu plants are nearly indiscernible to the casual observer from

seedling lima beans, soybeans and snap beans until they vine out. Vines can attain significant heights once they begin to climb, so it is important to also look up into tree canopies when searching for kudzu foliage. As such, any measures or materials to identify and train on kudzu must capture all stages of growth and appearance of the plant in botanical, cultivated and naturalised populations, and show the phenotypic and morphological differences between kudzu and similar looking legumes like soybeans, lima beans, and snap beans.

Rapid eradication of kudzu populations can be done through physical control based on digging out and removing kudzu's root crowns, which is the most appropriate method to manage early and small kudzu infestations.

Management of established populations: Efforts to control or eradicate established populations of kudzu are costly and labour intensive (Forseth and Innis, 2004). Chemical control using different herbicides is an effective control method and one of the most commonly used for controlling kudzu invasions. However, these products need to be approved for use and must be used with care when crops or sensitive plants, animals or habitats are located nearby; even when approved for use, they often cannot be used near aquatic habitats (Miller, 1996).

Chemical control can be coupled with other control strategies in integrated pest management programmes, which have been successful at suppressing kudzu. For the management of established and reproducing kudzu populations, it is essential that the boundaries of each spatially distinct kudzu site be determined before control measures are discussed, regardless of the age of the site. To kill a kudzu patch in a regulatory quarantine situation requires cutting the vines and ropes between knots and removing or killing crowns and all below ground tubers; and exhausting the viable seed bank. This can be done with a combination of mechanical and chemical measures described in further detail below (Bravo *et al.,* 2012a,b). However, biological control via grazing can assist with suppressing biomass and depleting root tuber reserves.

Biological control using insect or pathogenic organisms is ill advised, due to the importance of closely related legume food crops that would likely be a suitable host. Nevertheless, an integrated management programme combining the use of a fungal pathogen, *Myrothecium verrucaria*, with mechanical control and suppressive vegetation has been shown to be potentially effective at controlling kudzu in experimental plots (Weaver *et al.,* 2016b). Regardless of which measures are chosen, all seeds and seedling root stock and root tubers must be destroyed; or allowed to persist if the site is just too unstable (for example removal would make it worse, aggravating landslide risk).

Solarization, although not cost-effective for the control of large kudzu infestations, can be useful as a first treatment in relatively small infested areas or in areas where chemical control cannot be used (Newton *et al.,* 2008; Miller *et al.,* 2015).

ADDITIONAL INFORMATION:

Site specific forensic investigation over the last 70 years documents the consequences and costs of abandoning a crop such as kudzu: In the United States, kudzu seed was purposefully broadcast as an agriculture crop across millions of acres in multiple states for soil stabilisation purposes in the 1920s through the 1950s. In order to stop the practice, the crop was temporarily listed as a federal noxious weed in the 1970s, making it ineligible for crop loss indemnity payments. Shortly thereafter, the plant was removed from the federal noxious weed list, but remains a listed noxious weed of several states. Over time, as this practice faded from public memory and with the onset of 'invasive species' awareness, these 'abandoned' plantings are managed as unintentional introductions and spread by regulators, policy makers, researchers and weed control personnel.

In the southern United States, kudzu was sold as a forage crop seed and planted on millions of acres to be harvested as a crop or grazed as pasture. It was also sown for soil stabilisation purposes along road side shoulders, railroad grades, gullies and projects like the Tennessee Valley Authority.

But in Pennsylvania, iron ore slag holdings of the former Bethlehem Steele and a well-known stone quarry supplying stone for interstate construction were documented to have been seeded with kudzu during that time period (1920 – 1970), then sold as road stabilisation materials for major highway construction projects throughout the Mid-Atlantic. Decades later, this distinctive iron ore slag was frequently found beneath kudzu populations and trace back records documented a common source of unintentional spread via these construction materials purposefully seeded with kudzu seed and abandoned (forgotten).

Reports of kudzu invasion in the scientific literature and in news media publications in recent times have often overlooked and understated the significance of the seed dealer – government supported seeding of kudzu as a 'crop' over a period of 30 years.

Remnants of these populations, some of which have attained substantial horizontal and vertical distances, are widespread and common in the southern United States and also found in Pennsylvania, Delaware, New York, and Indiana along right of ways for railroads, highways, coal mine restoration sites and superfund sites.

The reports in the literature that millions of acres or hectares of land in the United States are infested are erroneous and should not be included in risk management

assessments. While it is true some 3 million acres were 'seeded' or 'seedling transplanted' (some 800 million seedling rootstocks were distributed) during this approved USDA program in the 1920s – 1950s, the vast majority of those cropped acres were rotated into another crop. What remain are fragmented populations of kudzu along hedgerows and field edges; along roadside shoulders and in ravines and steep banks throughout the southern states. As recently as 2010, the United States Forest Service published revised estimates that less than 240,000 acres remained in the southern United State forests. Other reports hover around 500,000 acres if all areas are combined, but those acreage estimates are just estimates, as ravines and gullies and roadside shoulder populations have not been measured.

Reports that kudzu has invaded the north due to climatic change are numerous but inaccurate. All kudzu sites in the United States are purposeful plantings or a result of the movement of seed in contaminated soil and stone. Kudzu is only wind dispersed short distances as a result of tornadic, hurricane events, and most waterways flow into the southern United States meaning water transport to northern states is unlikely. While wildlife may move kudzu seeds short distances in heavily infested areas of the southern united states, it is unlikely any such dispersal has occurred to northern states via this mechanism, as most sites of kudzu in surveys reveal purposeful, but abandoned, plantings.

However, as more and more abandoned or unmanaged populations attained maturity and produced viable seed, the spatial size of the parent populations' vegetative footprint has grown, as has early detection rapid response outreach resulting in the discovery of decades old populations. But it is also true that more people are planting kudzu regardless of regulatory restrictions for a niche market in edible and herbal commodities.

The 1990s national invasive species awareness campaign has since led to the discovery of forgotten populations of kudzu throughout the United States. In Illinois, 78 populations were recorded from 28 counties in 1997. In 2005, another six Illinois counties reported kudzu, all located in the southern half of the state (Aurambout and Endress, 2018).

The author of this document conducted a comprehensive survey and assessment of known and alleged kudzu sightings in the Commonwealth of Pennsylvania in 2006 and surveyed other states requesting confirmation on reported sightings in the literature. The last time Pennsylvania conducted a targeted survey for kudzu was in 1986.

The first recorded observation of viable kudzu seed production in Pennsylvania from an old growth site was by Will Mountain, state botanist in 1983, who collected the seeds and deposited them in vials in the State Herbarium. However, the USDA circular 89 (Taylor, 1929) and a September article in the 1920 Illustrated World entitled 'Oriental Immigrant from the Plant Kingdom' makes note that kudzu flowers and produces seed pods as far north as Philadelphia, indicating that in 1920 kudzu plants were flowering in Pennsylvania.

The importance of this observation is that the Pennsylvania site where seeds were collected in 1986 were still producing viable seed in 2005, allowing for thirty years of possible seed dispersal. Nearly all of those populations were still in existence thirty years later (Bravo *et al.,* 2009).

Despite the known length of time of kudzu present in Pennsylvania, the pilot kudzu eradication program in Pennsylvania comprehensively investigated every known or former location of kudzu in the Commonwealth and only identified 137 privately owned, government owned and commercial properties with 89 spatially distinct populations totalling no more than 70 acres in 19 counties, mostly in urban environments and along transportation corridors from Philadelphia to Pittsburgh and below the East to West Interstate 80 line. Kudzu clearly did not 'invade' Pennsylvania, nor has it become a widespread, common, invasive species in Pennsylvania.

Most sites infested multiple jurisdictional boundaries and for herbicide label use wording, 'multiple site descriptors' applied.

The state of Indiana also surveyed for kudzu, resulting in more than 100 sites discovered in 35 counties reported in 2008. The size and scope of these sites were very similar to the PA findings.

New York created a Kudzu Task Force that identified some 100 sites mostly in the Long Island-New York City region of the state, many of which were previously documented in various herbariums around the country. Surveys in other northern states followed suit and many old growth kudzu sites have been discovered in areas not associated with the seedling program in the south. A site now being managed in Canada using the Pennsylvania protocols was only recently rediscovered due to the recent resurgence of invasive species outreach in the United States.

Most of these northern range sites are classified by investigators as intentionally abandoned horticultural plantings or were known historical soil stabilisation plantings for transportation and utility right of ways.

Measures for preventing the species being introduced, intentionally and unintentionally.

This section assumes that the species is not currently present in a Member State, or part of a Member State's territory.

A ban on importing (pre-border measure), selling, breeding, growing, and cultivation, as required under Article 7 of the IAS Regulation, targeting intentional introduction of plants and propagules of *Pueraria montana* var. *lobata*.

MEASURE DESCRIPTION

As the species is listed as an invasive alien species of Union concern, the following measures will automatically apply, in accordance with Article 7 of the EU IAS Regulation 1143/2014:

Invasive alien species of Union concern shall not be intentionally:

(a) brought into the territory of the Union, including transit under customs supervision;
(b) kept, including in contained holding;
(c) bred, including in contained holding;
(d) transported to, from or within the Union, except for the transportation of species to facilities in the context of eradication;
(e) placed on the market;
(f) used or exchanged;
(g) permitted to reproduce, grown or cultivated, including in contained holding; or
(h) released into the environment.

Also note that, in accordance with Article 15(1) – As of 2 January 2016, Member States should have in place fully functioning structures to carry out the official controls necessary to prevent the intentional introduction into the Union of invasive alien species of Union concern. Those official controls shall apply to the categories of goods falling within the Combined Nomenclature codes to which a reference is made in the Union list, pursuant to Article 4(5).]

Therefore measures for the prevention of intentional introductions do not need to be discussed further in this technical note.

Inspection of all imports possibly containing viable *Pueraria* species and congeners.

MEASURE DESCRIPTION

Goal: Prohibit/prevent the voluntary/accidental importation of all species of *Pueraria* root tubers, seeds and plant parts, other than ground dried extract or products that do not contain viable parts.

Kudzu has been continuously imported or transported beyond its established range, as demonstrated by the number of occurrences found in the USA and elsewhere. However, as kudzu has limited distribution in the EU and is not a long distance dispersed species, prohibiting the importation of viable *Pueraria* species and cogeners, and their root tubers, seeds and plant parts, is the most cost effective measure to ensure this genus does not become widely established in this area. There are at least 20 congeners in *Pueraria* native to temperate and sub-tropical climates of Southeast Asia, indicating that efforts to prevent importation into the European Union should focus on all species and congeners of *Pueraria*, such as tropical kudzu, *P. phaseoloides* (Heuzé *et al.,* 2017), and not just on *P. montana*. Moreover, attention must be paid to not properly labelled plant material: for example, Plant Pest Officers of the USDA have frequently intercepted mislabelled 'arrowroot' products, which were determined by identifiers to be *Pueraria* plants or plant parts (M. Bravo, pers. obs.).

Many countries prohibit the movement of restricted plants and plant parts and have regulations pertaining to the export of fruits and vegetables to Europe. Regulations should be adjusted to prevent introduction of plant or viable propagules of *Pueraria*.

To implement this measure, the following actions should be taken:

- Inspect imported tubers and plants, in particular those labelled as 'arrowroot' (roots of *Maranta* sp. and *Zamia* sp.) and other 'yam like' tuber crops (roots of *Dioscorea* sp.) and 'tri-lobed legumes'; seed imports of small seeded legumes; other root crop seeds and root crop seed blends grown or harvested from crop fields in regions of the world where kudzu is extensively found as a weed of cultivated crops.
- Inspect imported used field and farm equipment and machinery, and equipment parts, from regions of the world where kudzu is extensively found as a weed of cultivated crops, as kudzu seeds and tubers can easily become stuck in crevices.
- Target mail order facilities and other ports of entry for canine inspection of packages or containers suspected of containing live kudzu tubers, roots and flowering plants (Teodoro-Morrison, 2014; Esch, 2019). Inspect shipments of tri-lobed flowering garden plants and plants labelled as *Maranta arundicaea*, *Zamia integrifolia*, *Cassava*, araru, ararao, or hulankeeriya.
- Routinely search for internet global sources and sales sites that might export the plant to Europe. For example, an internet search readily found *P. lobata* seeds advertised as Japanese arrowroot for sale on Etzy, eBay and some other botanical trading sites. Train port of entry canine units and their handlers to detect kudzu tubers, roots and flowering plants in luggage, containers and mail packages.
- Inform travellers and exporters/importers that seeds and live parts of kudzu are prohibited from importation and it is illegal to mail them, carry them in luggage or on your person.

SCALE OF APPLICATION

The scale of this application should include all ports of entry into Europe, including mail order shipments, but especially those ports that move considerable quantities of edible Asian vegetables.

EFFECTIVENESS OF MEASURE

Effective.

This measure is effective in relation to its objective. Plant pest inspections of edible fruits and vegetables, and of plant parts, to prevent the introduction of regulated pests, including weeds and their seeds, and of plant parts, is a standard global practice (McCullough *et al.,* 2006). Updating these policies and guidelines to include *Pueraria*, and informing travellers and exporters/importers, will reduce the likelihood of mislabelled kudzu roots and tubers entering the EU via for example the edible exotic food and exotic plant medicinal market. An example of one such measure is USDA's International Traveller: Plants, Plant Parts, Cut Flowers, and Seeds notification system[1].

The European Union has already begun to look at reducing the risk of invasive forest pests and pathogens by combining legislation, targeted management and public awareness (Follak, 2011; Klapwijk *et al.,* 2016), which can also be used for targeting invasive plant species.

1 https://www.aphis.usda.gov/aphis/resources/travelers-int/!ut/p/z0/fcwxC8IwEIbhX5OxXJSicytBFIugS5slnPXQaEjb3Fn031t0cnH6eODjBQs12Iijv6D4LmKY3NiF2-3z1aw86mlNqQtzWFbGbObrKoct2P-HqeBvw2ALsG0XhZ4CNfZXz-7DKC74U8L0UprRJeLukVpipSXhSIGS0j5KyL5Uug8YhTMmOvOvoL_b5g2_L474/

Pueraria montana (Pueraria lobata) © *Archive of Institute Symbiosis.*

EFFORT REQUIRED

Inspection of imports occurs daily at all ports of entry, and shipments of targeted commodities often peak at certain points in the year, which would allow inspectors to maximise the best use of limited resources. A review by Augustin *et al.,* (2012) on pest surveillance techniques provides detailed information of the most commonly used methods to detect plant pests at European ports of entry.

RESOURCES REQUIRED

Use existing cost estimates for port of entry inspection of goods and perishable commodities. However, it is worth noting that canines can detect kudzu (M. Bravo, pers. obs.) and, although an initial high cost of training canines to scent out *Pueraria* roots will be incurred (around $11,000 - 9,950 EUR; Glendale California Police Department, 2019), this is worth considering for mail order smuggling of live plant parts. Trained botanists experienced in Asian vegetable tuber and seed identification, with the ability to train inspection personnel on the characteristics of *Pueraria* species will be needed, as will identification manuals depicting the characteristics of similar looking legume species. Strategically, this training can address other invasive species of Union concern listed in EU Regulation 1143/2014.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Negative
Increased inspections and prohibitions of the importation of different *Pueraria* species might incur additional costs or a lack of revenue to exporters/importers and reduce the sale value of these species.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.
Importers, exporters and travellers are already accustomed to inspection of shipments and luggage for pests of concern and restricted plants and plant parts, so the measure should be acceptable to stakeholders.

ADDITIONAL COST INFORMATION

The cost of inaction is very high, as shown by the history of introductions, abandonment and control of kudzu in the USA.

Kudzu control costs in pine stands in Georgia, USA, exceed $200 (180 EUR) per acre per year for five years and control costs by power companies alone in the USA are estimated at $1.5 million (1.3 million EUR) per year (Britton *et al.*, 2002), with costs increasing over time.

State and site specific studies on the management cost of kudzu are commonly found in the literature (such as Aurambout and Endress, 2018) and cost estimates vary widely depending on if researchers modelled or applied measures, and whether or not they captured all phases of an early detection and rapid response (EDRR) plan.

LEVEL OF CONFIDENCE*

Well established.

Multiple independent studies agree that measures to prevent the importation of plant pests and invasive species of concern are well established, but are only as effective as the effort put into inspecting all sources likely to contain *Pueraria* roots, tubers, seeds and plants. Due to the ownership of ports of entry in Europe by Chinese firms and the thriving expanding Asian food market in Europe, the challenge to intercept an easily hidden root tuber such as kudzu is dually noted.

* See Appendix

Measures to prevent the species spreading once they have been introduced.

Prohibit the movement of contaminated soil, stone and field equipment from areas known to have kudzu.

MEASURE DESCRIPTION

Goal: Have the ability to quarantine or issue control orders for individual infested sites and sites that cross multiple jurisdictional boundaries and properties. Once quarantined, evaluate the site and determine the best course of action based on the site descriptors (cropland, fallow, orchard, garden, lawn, forested, wetland, superfund site, ornamental landscape bed, road right of way, rail road right of way etc.).

While kudzu does spread spatially over time, new populations in the United States are usually associated with transport of contaminated soil by road side and agriculture equipment, flood water depositions, high wind dispersal of mature seed pods, or secondary spread from spatially distinct parent populations via parent population severance and subsequent deposition of viable plant parts and seed by road equipment (mowing, snow removal, grading, construction earth moving activities).

Several studies on kudzu in the United States have acknowledged the movement of kudzu seeds, root tubers and plant parts does occur in soil moved from one location to another by localised flooding and construction equipment. This has been and continues to be a frequent method of dispersal in the United States, where kudzu was purposefully and legally sown since the early 1900s through the 1970s. Viable root tubers and root crowns are moved as weeds during tillage and on tillage equipment, and very short distances by grazing and localised flooding of crop fields previously planted with this perennial legume. While the adoption of no-till and the recognition of kudzu as a noxious or invasive weed has significantly reduced movement in this manner in the United States, kudzu is still found growing along road shoulders that are graded, in abandoned forgotten mounds of earth that are then 'dozed over' and also in stone and rock piles where it was purposefully seeded for erosion control (Bravo *et al.,* Pennsylvania CAPS Survey Kudzu Eradication Program annual reports, unpublished).

Another source of movement is via used idled farm equipment, specifically farming equipment and vehicles parked in or by a kudzu site, or used to harvest a crop where kudzu is a weed. The former is common where kudzu draped hedgerows have grown over and into junked equipment. Kudzu seeds and kudzu root knots get lodged in the equipment and may, or may not, dislodge during transport (Barth, 2016).

Kudzu planting in private or public (botanical) gardens was a frequent practice for several decades. Abandonment of these sites resulted in decades old growth kudzu vines of considerable dimension producing viable seed from seed pods suspended high in the air, which are potential sources of invasion.

Following kudzu management actions by cut or removal intervention (in botanical plantings, gardens or any other areas), the movement or abandonment of contaminated materials or of the plant as waste can also promote secondary spread.

To implement this measure, the following actions should be taken:

- Prohibit or issue control orders for the movement of contaminated soil, stone and field equipment from sites known to be infested with kudzu.
- Prohibit or issue control orders for the movement, and forbid the release/abandonment in nature, of contaminated materials and plant waste from sites undergoing kudzu management actions, or impose specific procedures to deal with them (for example AGIN, 2015).
- Require garden owners or managers of kudzu invaded areas, and those moving used field and forestry equipment known to have been used, or stored, in regions known to have kudzu as a weed of cultivated crops and timber stands, to complete a step by step instructional form designed to mitigate the accidental movement of kudzu seeds and root tubers. Raise awareness of the general public (such as farmers and gardeners) by, for instance, creating coloured pest flash cards depicting key characteristics of the flowering kudzu vine: the vine; seed pods and seeds; root tuber and distinctive liquorice-anise like odour.

Rare, but documented cases of kudzu seedpods and or seeds being dispersed in tornadic winds have occurred. Localised storms, tornadoes and other high velocity wind events can transport kudzu seeds short distances in updrafts and downbursts from locations where the species exists

(Bravo and Miller, 2010). This was observed in a site in Pennsylvania, where a tornado touched down in a hedgerow and a few seedling kudzu plants were discovered vining out in a drive-by (M. Bravo, pers. obs.). The risk of tornadic distributed kudzu seeds from southern to northern states in the USA cannot be discounted in the future, as more and more tornadic outbreaks are occurring in the northern United States. A similar trend seems to occur in the EU, where very severe windstorms are even more frequent, highlighting the importance of this potential pathway of secondary spread in the future (C. Montagnani, pers. comm.).

SCALE OF APPLICATION

Prohibition of movement off site of contaminated soil and other earth laden materials is a common measure in managing kudzu infestations in the United States. Spatially distinct populations of abandoned botanical plantings and road side shoulder seedings are more easily delineated and quarantined than acreage infested (forests, right of ways, crop fields).

In Pennsylvania, USA, all sites enrolled in the Kudzu Pilot Eradication Program were prohibited from moving contaminated soil and plant parts without a permit by the authority of state plant pest regulations (Bravo, 2008, 2009; Bravo *et al.,* 2009, 2012a,b; Bravo and Miller, 2010), although contaminated soil and plant parts were frequently dug out or buried, as the most cost effective and 'acceptable to all stakeholders' measure of control.

EFFECTIVENESS OF MEASURE

Effective.

Highly effective in preventing secondary spread, if enforced. However, as road side shoulder populations, in particular, are routinely disturbed by snow plough grading and vegetation mowing, particular attention should be given to sloped sites adjacent to transportation corridors.

For example, in Pennsylvania, USA, a single kudzu population along a state road was repeatedly cut by road equipment and deposited further along the route for miles in both directions over the course of fifty years. Once the sites were quarantined in the pilot kudzu control program and the municipality, highway department, and all property owners were made aware of the restriction, no new populations occurred and existing populations were quickly eradicated, using a combination of state funds and like kind match from all impacted stakeholders (Bravo, 2008, 2009; Bravo *et al.,* 2009, 2012a,b; Bravo and Miller, 2010).

EFFORT REQUIRED

Quarantine of infested sites (soil, vegetation, junk, structures) must be kept in place until all above ground and below ground biomass are declared eradicated. However, in many instances, only a declaration of 'controlled to prevent seed set' is possible and acceptable and, in other instances, no control is advised due to the nature of the site (superfund site; highly erodible slope), thus the quarantine is perpetual.

A simple solution to movement of contaminated equipment from the quarantine site (equipment destined for sale or repurpose) is to require it to be thoroughly cleaned of plant parts, allowing for its quick release.

RESOURCES REQUIRED

Quarantine orders can be prepared in advance, allowing for the specifics of each site to be pencilled in during the survey and assessment. A property packet detailing the program, the results of the delineated survey and the various measures and costs are a very cost effective way to gain responsible party buy-in. Quarantine tape and metal signs denoting the site as a regulated pest can be ordered in bulk and be used as needed.

SIDE EFFECTS

Environmental: Positive
Social: Negative
Economic: Negative

Prohibiting the movement of contaminated soil and field equipment from kudzu infested areas might prevent the spread of other invasive plant species. However, it can also have negative effects on land owners, who are not able to freely move soil or machinery from their infested land, which can incur additional costs.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

For soil health and agriculture productivity, the benefits of kudzu's quick cover cropping establishment and nitrogen fixing capabilities are highly desired on poor quality, highly eroded soils, even if in Europe plants other than kudzu have been traditionally and more widely used. In addition, the marketing and awareness of kudzu as an edible Asian root vegetable, its herbal and medicinal value is increasing rapidly, and resistance to banning it completely should be anticipated in the future.

As such, to prevent misconceptions, and for stakeholders and the impacted responsible party buy in, quarantine to restrict the movement of kudzu must be clearly explained to the public, as to why the kudzu site poses an environmental harm, is a social nuisance and the costs associated with controlling an escape from cultivation.

ADDITIONAL COST INFORMATION

Cost of inaction is high, as secondary spread of abandoned kudzu infestations is the quickest route of establishment of spatially distinct populations that can then be further distributed by high wind events and movement by humans.

LEVEL OF CONFIDENCE*

Well established.

There are multiple independent studies that agree that quarantines of soil and contaminated materials are a standard measure to mitigate movement of plant pests and plant pathogens (Webster, 2006).

* See Appendix

Measures for early detection of the species and to run an effective surveillance system to detect efficiently new occurrences.

Targeted plant surveys/inspections assisted by public participation.

MEASURE DESCRIPTION

Kudzu is an easily recognised vining legume that expands its range vegetatively and by explosively dispersing seeds from pods hanging from vines that have climbed as high as they can go. For regulatory enforcement, keying out *Pueraria* to genus in the field is sufficient; keying out to species level or congener would be impossible without laboratory assistance. The difficulty lies in identifying tubers and seedlings from other legume crops and root crops of the same morphology. The tuber shape of kudzu roots can easily resemble other root crops; only a trained individual would discern a mislabelled root tuber from similar looking edible vegetables. To the casual observer, seedling kudzu plants are also nearly indiscernible from seedling lima beans, soybeans and snap beans, until they vine out. Vines can attain significant heights once they begin to climb, so it is important to look up into tree canopies when searching for kudzu foliage. Old growth vines are tree like in their structure and are difficult to discern, as the ropes mimic sapling forms. Finding the root crowns in the soil-debris interface is challenging. Seeds of kudzu are very small and would easily be missed in a legume mixture, unless trained to identify them.

As such, a surveillance program, if not performed only by experts, will require that individuals experience a living infestation to train their eyes on what to look for to maximise resources. One of the ways to do this is by allowing a botanical specimen to be cultivated for research purposes, as is done in the United States for 'weed' collections at land grant universities. Furthermore, kudzu requires a long growing season to flower and some time to establish enough root reserve to flower, so all growth stages of the plant must be depicted in identification materials. As such, any training materials on how to identify kudzu must capture all stages of growth and appearance, and show the phenotypic and morphological differences between kudzu and similar looking legumes like soybeans, lima beans, and snap beans.

To implement this measure, the following actions should be taken:

- Inspect fields of seed production breeder and of research trials of small seeded legumes and other root crop seeds grown from seed sources obtained from crop fields in Asia and South-eastern USA (specifically Tennessee, North Carolina, South Carolina, Georgia, Mississippi, Alabama) for the presence of kudzu seeds and tubers; or any breeder who acknowledges growing kudzu for research and seed propagation prior to the EU IAS Regulation entering into force, particularly if a seed dispersing weather event (tornado, hurricane or tropical storm) occurred in the area.
- Survey private or public gardens (and their surroundings) where kudzu has been cultivated before the EU IAS Regulation entered into force. Attention must also be paid to sites where green waste is legally or illegally discharged.
- Train the general public on kudzu identification by for example creating coloured pest flash cards depicting key characteristics of all growth stages of the kudzu vine and disseminate information regarding the regulatory status of kudzu, why it is of concern and where to report suspected sightings.
- Send weed alerts to stores that sell seeds and live plants, botanists, landscape architects, garden enthusiasts, vegetation control personnel and right of way managers to be on the lookout for and report any occurrence of this distinctive climbing vine.
- Promote the use of citizen science applications, such as the 'Invasive Alien Species Europe' JRC app[2] and other pre-existing apps to report new sightings of kudzu.

SCALE OF APPLICATION

Regular kudzu inspections should be incorporated into existing plant pest detection surveys. Kudzu weed alert materials should also be incorporated into pest training resources and disseminated to the general public, Asian

2 https://digitalearthlab.jrc.ec.europa.eu/app/invasive-alien-species-europe

food markets, restaurants, plant nurseries and crop seed businesses.

EFFECTIVENESS OF MEASURE

Effective.

All states in the USA have surveyed for and identified new populations of kudzu using these measures. The measures are effective if the investigators understand the biology and ecology of kudzu, and properly measure the spatial footprint of the parent population. The classification of the infestation must also be properly denoted (seedling, seed stock, root tuber planting; abandoned botanical planting; seed rain dispersal etc.). Failure to delineate the parent population from separate distinct populations not connected by vegetative parts results in the failure to manage closely situated, but distinct infestations. Knobby ropes often grow just below the soil surface and hide along tree roots and stone walls, or under buildings like 'snakes'.

Hotlines and media outreach on kudzu, during the peak of flowering, often return positive discoveries and serve to mass educate the population on look-alike plants and the concerns over invasive species in general. Agency press releases coupled with timely media articles (for example Crable, 2007; Bravo, 2008, 2009; Bravo *et al.,* 2009, 2012a,b; Bravo and Miller, 2010) have proven very successful in assisting survey crews to find previously unknown kudzu sites, highlighting the potential of citizen science to have the same effect.

EFFORT REQUIRED

This measure should be applied indefinitely.

RESOURCES REQUIRED

As many staff, vehicles and landowner informational packets as necessary to execute a land survey of this kind.

The Pennsylvania program utilised multiple locally based seasonal personnel to systematically survey known kudzu sites and surroundings, research herbarium and literature records. A two person team of trained applicators went through the state visiting sites on a regular schedule and applying control measures, while at the same time working on other targeted species of concern in the USA (giant hogweed, goatsrue, mile-a-minute) (M. Bravo, pers. obs.).

Resources would also be required to train the general public on kudzu identification and to promote media outreach actions.

SIDE EFFECTS

Environmental: Positive
Social: Positive
Economic: Neutral or mixed

Promoting participation of the general public on invasive plant surveys educates the population on the concerns over invasive species in general and might promote the detection of other invasive alien plants.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Public and landowner perception regarding discovery of viable kudzu plants and plant parts is quite variable and dependent upon the pathway of introduction (purposeful introduction before regulatory enforcement, contaminated soil, found on property after purchase, mislabelled botanical planting, food market purchase, internet purchase). There might also be privacy issues raised when surveying for kudzu as a regulatory pest of concern, as surveys to detect kudzu must take into account the backyard and flowerbeds of private residences.

If the governing authority has access to an invasive species task force and strike team that has the ability to implement EDRR plans across multiple species, the results are highly positive. The lack of trained professionals capable of performing and implementing kudzu surveys, assessment and control creates significant frustration amongst stakeholders and impacted property owners.

ADDITIONAL COST INFORMATION

The cost of inaction is well documented as being strongly negative in the southern United States, as these states are still battling with legacy kudzu infestations in forests, pastures, on private properties and along highways and byways. The Alabama and Auburn Extension has an online blog[3] that summarises the history of kudzu's impact on the South.

LEVEL OF CONFIDENCE*

Well established.

Multiple independent studies agree that early detection rapid response surveys are highly effective in discovering this 'hiding in plain sight' crop on multiple properties, when combined with outreach and education efforts that alert the general public to the concerns over abandonment of this perennial legume vine.

3 https://www.aces.edu/blog/topics/invasive-species/history-use-of-kudzu-in-southeastern-united-states/

* See Appendix

Measures to achieve rapid eradication after an early detection of a new occurrence.

Physical control.

MEASURE DESCRIPTION

The method used to rapidly eradicate small areas or a few botanical plantings of kudzu is to cut off the above ground foliage (climbing vines) from the root and dig out roots (when feasible, based on the plant and infestation size) or completely remove all the root crowns. For this, first all rooted crowns within the site must be found and tagged, and then tap-rooted crowns of individual seedling plants should be dug out and removed. Kudzu root crowns can be completely removed by hand, or pried up and cut from the vines and roots by using tools such as hoes, mattocks and pruning saws. When the root crown is extracted, the resprouting capacity of the plant is drastically limited and it progressively becomes weak and dies (impossibility to store adequate resources in the roots). By using this method, the removal of the long tuberous tap roots is not strictly necessary (Miller *et al.,* 2015; http://kokudzu.org/SurgicalRemoval.html). Root crowns should be placed in the sun, not in contact with soil, to dry out and die. Every kudzu plant in and around a patch must be killed, in order to prevent spread from any surviving plants and guarantee eradication (Miller, 1996). In case a viable soil seed bank is present, monitoring and further interventions will be necessary to achieve successful eradication.

In Switzerland, Morisoli *et al.,* (2018) conducted trials using physical control at two kudzu heavily infested sites. For this, first kudzu foliage was removed by hand to ensure accessibility and to help identify rooted crowns. Then, all the root crowns were removed by cutting the roots a few centimetres below the crown with a folding hand pruning saw. To eliminate the nodes still active, this was repeated one month later, and in the following growing season once a month from May onwards. In a different part of Switzerland (Canton Ticino), a very similar protocol was used in three different areas of kudzu infested sites (Frisoli and Crosta, 2017).

SCALE OF APPLICATION

In Switzerland, this method was used in two experimental fields: in one case on four plots of 5 × 3 m (Morisoli *et al.,* 2018) and in the other on a total area of 2,700 m^2 divided into three distinct areas (Frisoli and Crosta, 2017).

EFFECTIVENESS OF THE MEASURE

Effective.

This measure has proven effective at eradicating small kudzu stands in the USA. A test site where kudzu crowns were removed in 2005 showed no regrowth and kudzu to have been completely eradicated from the area in 2006 (http://kokudzu.org/SurgicalRemoval.html).

In Europe, one of the studies performed in Switzerland showed a progressive reduction in the number of plants per m^2, almost reaching a total effectiveness after 2 years of interventions (Morisoli *et al.,* 2018) and a similar result was observed for the other study undertaken in the Canton Ticino, which allowed up to 90% of kudzu root crowns reduction within 3 years (Frisoli and Crosta, 2017). It is important to note that both these studies were undertaken in kudzu highly infested areas, which might have limited their effectiveness.

EFFORT REQUIRED

Very small kudzu sites and individual botanical plantings can potentially be controlled in one visit, although post-intervention monitoring is highly recommended. On the other hand, larger infestations would require considerable time and effort to remove all kudzu rooted crowns, as these sites can have thousands of them. In these cases, the investment in time is maximum in the first intervention and drastically reduced during the following control visits to eliminate residual or previously dormant rooted crowns, so it can take up to two years of follow-up treatments to permanently eliminate kudzu (Morisoli *et al.,* 2018; http://kokudzu.org/SurgicalRemoval.html).

RESOURCES REQUIRED

The costs of this measure largely depend on the area to be treated, because they mainly concern the payment of personnel to undertake the physical work. Depending on the nature of the site and on the size of crowns to be removed, a trained worker removes from 10 to 50 crowns per hour, making this method unpractical or too costly, unless several people, or volunteers, work at a site. Considering these costs, this measure can be more expensive than applying chemical control (http://kokudzu.org/SurgicalRemoval.html).

The tools used are widely available and cheap ($16-19, approximately 15-17 EUR).

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed
As this method is selective, the only potential side effects resulting from this measure are soil disturbance.

ACCEPTABILITY TO STAKEHOLDERS

Acceptable.
This measure should be acceptable by all stakeholders, as it does not have any negative side effects and is easy to apply.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE*

Established but incomplete.
This measure is agreed to be effective at eradicating small kudzu infestations, but more studies testing its effectiveness, especially in Europe, are needed.

* See Appendix

Measures for the species' management.

Chemical control.

MEASURE DESCRIPTION

Several herbicides, such as picloram, metsulfuron methyl, aminopyralid, aminocyclopyrachlor, clopyralid and triclopyr have been shown to be effective in long-term kudzu suppression and have been used for the management of established kudzu populations (Miller, 1996; Harrington *et al.,* 2003; Minogue *et al.,* 2011; Miller *et al.,* 2015; Weaver *et al.,* 2016a,b; Morisoli *et al.,* 2018). Kudzu eradication using chemical control is also possible but, for this to be achieved, it is fundamental that all rootstocks are completely controlled, otherwise they can emerge again after some years (Minogue *et al.,* 2011).

Herbicides can be applied at different rates, different times of the year and recurring to the use of different techniques and equipment, such as by spot spray or broadcast application, using backpack sprayers, ATVs equipped with spray systems or tractor-mounted sprayers. For examples of different protocols used to chemically control kudzu, see for example Miller *et al.,* (2015) for examples in the USA and Morisoli *et al.,* (2018) for a preliminary trial in Europe.

Herbicides should always be applied according to exact label instructions and requirements, and should comply with EU and national regulations. It is important to note that kudzu populations in Europe are often present on the banks of lakes or rivers (C. Montagnani, pers. comm.), so the use of herbicides that have substantial non-target effects on aquatic environments (for example picloram) should be avoided.

SCALE OF APPLICATION

The scale of application of the measure depends on the area invaded by the plant. If eradication is desired, every kudzu plant in and around an invaded area must be destroyed to guarantee that no surviving plants remain (Miller, 1996).

EFFECTIVENESS OF MEASURE

Effective.

Chemical methods have been shown to be effective in controlling, or even eradicating, established kudzu populations (such as Miller, 1996; Harrington *et al.,* 2003; Minogue *et al.,* 2011; Miller *et al.,* 2015; Weaver *et al.,* 2016a,b; Morisoli *et al.,* 2018).

For example, Weaver *et al.,* (2016b) showed that it is possible to achieve localised control of aboveground kudzu biomass in 2 years through the use of different combinations of commonly used (metsulfuron methyl and aminopyralid) or new, selective herbicides (aminocyclopyrachlor + metsulfuron methyl and aminopyralid + metsulfuron methyl). The metsulfuron methyl and aminopyralid treatments, some of the most commonly used in kudzu management, were highly effective, resulting in >90% reduction in kudzu biomass after 1 year and 99% after a second year of application. The two new product formulations tested (aminocyclopyrachlor + metsulfuron methyl and aminopyralid + metsulfuron methyl) also provided excellent kudzu control after three applications, when over 99% control was achieved. A third herbicide-intensive programme tested (using various combinations of products) resulted in 100% control at all test sites after 2 years (Weaver *et al.,* 2016b).

Similarly, a preliminary study in Switzerland has shown that herbicides using either triclopyr, or clopyralid + picloram at the right concentrations, applied in 2 consecutive years, showed 100% efficiency in controlling kudzu populations from the first application (Morisoli *et al.,* 2018).

EFFORT REQUIRED

Due to its extensive rooting, kudzu management using chemical control typically requires many years of repeated herbicide application. For complete eradication, up to 10 years of herbicide treatment may be required (Miller, 1996). Nevertheless, Morisoli *et al.,* (2018) have shown that it is possible to achieve control of small kudzu patches after 2 years of herbicide treatment.

RESOURCES REQUIRED

The resources required in order to apply this measure consist of trained staff to apply herbicides, the costs of the chemical products and different types of chemical broadcasting machinery/tools. Herbicides are generally expensive and require repeated and thorough applications.

SOCIAL EFFECTS

Environmental: Negative
Social: Neutral or mixed
Economic: Neutral or mixed

Herbicides can be detrimental to humans, domestic animals, desirable plants, or other wildlife, especially if not handled properly, so they should be used selectively and carefully (Miller, 1996). Clopyralid is often recommended when safety

Pueraria montana (Pueraria lobata) © *Matt Lavin. CC BY-SA 2.0.*

of other vegetation is desired or where the use of persistent soil-active herbicides is not appropriate (Minogue *et al.,* 2011). Environmental side effects can also be reduced through the use of recent and more selective herbicides, such as aminocyclopyrachlor (Weaver *et al.,* 2016b).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Stakeholders and the general public are often against the application of chemical control measures, due to their potential side effects. However, in the case of kudzu infestations, the more rapidly eradication is achieved, the sooner the infested land can be returned to economic or ecosystem productivity (Weaver *et al.,* 2016b).

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE*

Well established.

Several studies have shown chemical control through the use of herbicides to be adequate and effective in controlling kudzu populations (see references and examples above).

* See Appendix

Integrated pest management (using mechanical, biological and chemical control).

MEASURE DESCRIPTION

This measure can be used both for the management and eradication of kudzu populations. For large infestations beyond what is feasible to dig out with a shovel or bulldozer, the goal must be to prevent seed set while eradication occurs. The steps to follow are to delineate; cut vines; spray crowns or dig out crowns; repeat until the site is negative for regrowth and/or seed germination. It would be acceptable, if so desired, to feed the biomass to livestock as a means of disposal, so long as the site did not set seed. But kudzu quickly wilts and botulism poisoning of livestock would be an issue, so cutting and feeding it would not acceptable, unless it was harvested as a forage crop and dried or ensiled appropriately (M. Bravo, pers. obs.).

This approach utilises multiple measures to exhaust the plants above ground and especially below ground biomass (Britton *et al.,* 2002; Bravo and Miller, 2010; USDA, 2016). The protocol of the five year Kudzu Eradication Program implemented in Pennsylvania, USA (Bravo *et al.,* 2012b), is outlined below:

1. Quarantine and delineate the boundaries of each spatially distinct 'parent' population. The following measures were used together to prevent secondary spread of kudzu in Pennsylvania.
2. Conduct a comprehensive trace back of all movement of soil, plants, plant material from the site based on visual and verbal information provided by property owners before and after the discovery.
3. Describe the site. Determine if the site every flowered and produced viable seed (such as a seed bank) or if the site is a vegetative transplant that may have flowered but never produced viable seed.
4. Knock down the above ground foliage if discovered during the growing season by means of mechanical, chemical or even biological control using animals. All types of grazing animals will readily eat kudzu, with cattle hogs, and horses eating the tender new shoots, while only goats and sheep will eat semi-woody and woody vines (Miller, 1996; Miller *et al.,* 2015). Find and tag all rooted crowns and root knots within the site.
5. Hand dig tap-rooted crowns of individual seedling plants in the year of establishment, desiccate and discard.
6. Spot treat above ground foliage and surface crowns with an in crop, fallow, or industrial site labelled herbicide (clopyralid, triclopyr, aminocyclopyr) using a combination of high volume foliar, low volume foliar, hand bottle and mechanical cutting measures (as described below). Review of the existing maximum residue levels for triclopyr according to article 12 of regulation (EC) No 396/2005 indicates the maximum use rate for triclopyr is sufficient to use on kudzu as a spot treatment. Garlon products, Milestone, Escort, Oust Extra and Roundup were also used depending on individual site characteristics, flora, fauna, ease of access, soil slope and property owner preferences (Bravo *et al.,* 2012b).

Example of one of the most commonly used Kudzu Treatment protocols in the Pennsylvania Program (Bravo *et al.*, 2012b).
Clopyralid: Transline Herbicide Active Ingredient: 3,6-dichloro-2-pyridinecarboxylic acid, monoethanolamine salt 40.9% Other Ingredients 59.1% : Total 100.0% Acid Equivalent: 3,6-dichloro-2-pyridinecarboxylic acid - 31% (3 lb/gal)
1. High Volume Foliar, 13.68 oz per acre Skid Mount / Gas Powered Turf Sprayer - 375 Litre (100 US Gal) Hypro Medium Pressure Diaphragm Pump: 100 gal/acre delivery@16 psi Transline (clopyralid) (10.26 oz) Water (75 gal)
2. Low Volume Foliar 2% v/v Birchmeyer Backpack (2.5 gal size) Transline (clopyralid) (6.0 oz) Water (2.5 gal)
3. Cut Stump/Basal Bark 2% v/v Plastic Bottle (16 oz size) Transline (clopyralid) (0.24 oz) Water (12 oz)

7. For established plants that have over wintered, identify all root crowns and rope knots with tags; cut and apply a concentrated spot application of herbicide directly to the cuts; or bury the site if topography and circumstances permit (dig a hole, scrape site into it; cover).

8. Do not use picloram or long lasting soil residual N-sulfonylureas for kudzu control (due to groundwater pollution concerns), unless the site slope and depth to groundwater can tolerate a sterile seed bed for a considerable amount of time (Berisford *et al.,* 2006; Bravo, 2008).

This management protocol takes advantage of the natural seed bank of monocots and other forbs present in the soil

seed bank and, as the kudzu biomass is reduced, they will naturally flourish. However, controlling this desired vegetation becomes a management cost, as it is necessary to have no competing vegetation present in invaded sites in order to find the kudzu root crowns. Managers can, of course, add to the native seed bank by seeding in a fast growing grass species to increase soil stability but, by doing so, this adds to the cost of controlling kudzu by preventing discovery of crowns and hiding the ropes and crowns that must be individually found and treated. The application of the herbicides to control kudzu may not coincide with conditions suitable for managing the cover crop, which is why any seeding of the site must take into account the long term management of the kudzu to achieve eradication.

SCALE OF APPLICATION

Thousands of acres seeded to kudzu and hundreds of spatially distinct former plantings have been managed or eradicated in the United States using these or similar measures that combine a growth regulator herbicide with mowing and removal of the roots and tubers, or a combination thereof. However, just as many sites have not been eradicated and are not managed, as the range of topography that kudzu inhabits in the United States is broad and frequently includes railroad grades, gullies, stream banks and other difficult to reach sites with perilous slope and unstable soils (which is why kudzu was 'seeded' at said location).

Kudzu sites can range from a container plant, a single arbor in a homeowners garden, a manicured hedge in a botanical garden, a linear infestation along a road shoulder, a linear infestation along forest edges, to acres of land or pasture if seeded as such. The scale of the application is directly proportional to the size of the infestation.

EFFECTIVENESS OF MEASURE

Effective.

Thousands of acres seeded to kudzu and hundreds of spatially distinct former botanical plantings have been managed or removed in the United States using these measures or a combination thereof (M. Bravo, pers. obs.).

Since USA's national movement to address invasive species, many of the country states have utilised invasive species management plans similar to the examples given here. The Pennsylvania kudzu control protocol was highly successful and the information gleaned in managing these northern populations may be of interest, as Pennsylvania is quite similar in climate to the European Union.

For example, a Bethlehem Steele (American steel and shipbuilding company) slag enforced roadside shoulder and adjacent decades old slag storage piles in south eastern Pennsylvania were unsuccessfully controlled for decades until 2008, when the site was enrolled in the Pennsylvania Pilot Kudzu Control Program mentioned above, with funding from the state legislature. After the parent canopy was prevented from producing viable seed using this protocol, the seed bank continued to produce plants for three years. However, 90% of all seed germinated in the first August flush after the parent canopy was removed, and no seedlings emerged in years four, five and six, indicating the seed is short-lived. This information was shared with other USA states (Maryland, Delaware, New Jersey, Ohio, Indiana, and New York and Canada), where similar measures were undertaken, resulting in successful control of decades old kudzu sites (USA State kudzu task force representatives, pers. comm.).

Another site in Pennsylvania, a stone quarry outside of Philadelphia, was ultimately treated with a combination of herbicides for three years. To reduce the need for follow up visits, a big hole was dug in the stone quarry and the infested soil material buried after no viable regrowth had occurred (Bravo, 2008, 2009; Bravo *et al.,* 2009; Bravo and Miller, 2010).

EFFORT REQUIRED

Multiple application windows are necessary to fully knock down a spatially broad site of kudzu. If seed rain has occurred within the site, it can take up to three years for all viable seed to germinate, although most germinate in the year of dispersment. Individual botanical plantings can be controlled in one visit, if not abandoned; purposefully seeded crop fields, on the other hand, would require considerable time and effort to remove all root tubers and plant parts from the crop fields. Due to its extensive rooting, repeated physical removal and herbicide application over several years (up to 10 years) are required to control this kind of kudzu infestations (Forseth and Innis, 2004). That is why digging the site out is often more cost effective.

The creation of a non-public (privacy issues) kudzu site specific GPS database for monitoring purposes is necessary to ensure that abandoned plantings do not revegetate the site over time.

Kudzu control will take longer in sub-tropical regions without significant cold temperature stress, and shorter in the northern latitudes of its range.

RESOURCES REQUIRED

Efforts to control or eradicate established populations of kudzu are costly and labour intensive (Forseth and Innis, 2004). Millions of dollars have been spent in the last 100 years controlling unwanted kudzu plantings in the United States (M. Bravo, pers. obs.).

Implementing these measures may entail a single shovel, multiple people digging, the use of a backhoe, a tractor and plough coupled with a single backpack sprayer or hand held bottle, to a large commercial boom sprayer capable of covering hundreds of feet or a high volume foliar sprayer

capable of spraying hundreds of feet up into the tree canopy. Mowing kudzu vines that are linear entails using hand held shears, lawnmowers, field mowers or, if so desired, animals. Removing vertical kudzu vines entails using hand held shears, chainsaws or high volume foliar herbicides.

For the chemical part of the treatment, according to the Pennsylvania control program, the cost of clopyralid is $212.00 per gallon, $105.95 for a half gallon and $1.66 per ounce (approximately 190, 95 and 1.5 EUR, respectively). The cost per acre to treat kudzu in one growing season with 16 ounces of product would be $26.56 (24 EUR), which is the maximum per acre restriction for Transline in Pennsylvania. However, this maximum rate was rarely used and often controlled sites used no more than 8 ounces per acre per growing season, repeated for three years, until all tagged root crowns were treated and the soil seed bank exhausted (Bravo *et al.,* 2012b).

Pennsylvania received a one-time $50,000 (45,235 EUR) line item in the state budget to survey all known sites, assess and enrol infested properties in a three year pilot eradication program using existing state employees full time (2) and seasonal staff (2) (Bravo, 2008, 2009; Bravo *et al.,* 2009, 2012a,b; Bravo and Miller, 2010). It was estimated that three times that amount annually, for five years, would be necessary to expand the program to target for treatment the acreage (excluding superfund sites and railroad right of ways etc.) due to the number of urban populations near Philadelphia and Pittsburgh metro areas. Site specific costs are more applicable for multiple property – multiple site descriptor infestations vs. the typical cost per acre units given for other weeds.

Estimates of $100-$200/acre (90.5-181 EUR) are not uncommon for acreage clearing and/or chemical control of kudzu in the south USA, where acreage infested is treated like any other crop weed. But inner-city/urban interface sites, like those in Pennsylvania requiring micro-management and regulatory compliance paperwork to protect desirable species, are easily in the $300/acre per day (271 EUR), per site, cost over multiple visits, over multiple years.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

The herbicides most cost-effective on kudzu are growth regulator products (Britton, 2002; Bravo and Miller, 2010; Berisford *et al.,* 2016) that control many broadleaf plants, not just kudzu, allowing many desirable tree species and grasses to flourish. While there are certainly other modes of action that work on perennial legume species, they are site and habitat limiting and many have long soil residuals and/or water quality warnings. An acceptable level of harm to desirable species comes with the decision to apply these products and/or to use mechanical control which, in itself, may destroy more desirable vegetation and infrastructure than is warranted. The larger the area infested, the higher the risk to desirable species from control measures.

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Stakeholders and the general public are often against the application of chemical control measures, due to their potential side effects. However, the more visible the area infested, the more public pressure to manage the site will occur, both of which increase the economic cost of control.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE*

Well established.

Multiple independent studies agree that kudzu can be controlled and eradicated over time using multiple measures to exhaust the above ground and below ground biomass of the species (Britton *et al.,* 2002; Bravo and Miller, 2010; USDA, 2016).

* See Appendix

Integrated pest management (using mechanical, biological control and suppressive vegetation).

MEASURE DESCRIPTION

An experiment has shown that it is possible to achieve rapid localised control of aboveground kudzu biomass through the use of an integrated treatment involving mowing, the use of bioherbicides and revegetation of the infested sites (Weaver *et al.,* 2016b). This treatment does not involve the use of synthetic herbicides, instead relying on the use of the bioherbicide/biological control agent fungus *Myrothecium verrucaria*, in combination with mowing and revegetation with switchgrass (*Panicum virgatum*). This method was designed to kill as much kudzu as possible, as rapidly as possible, and to maintain season long pressure on any recovering plants (Weaver *et al.,* 2016b).

In case this measure is considered for use in the EU, caution should be taken given that *M. verrucaria* is a fungal pathogen capable of damaging important crop species (Garibaldi *et al.,* 2016). Furthermore, *P. virgatum* is a species native to North America, but alien to Europe, so the selection of an alternative native herbaceous perennial species would be required. This selection must take into account the resistance of the perennial species to bioherbicides, which could also influence the management protocol (for example time of seeding).

This measure consists in 1) mowing kudzu plots using an All-terrain vehicle (ATV)-pulled mower, 2) planting switchgrass transplanted in the field at a density of 1.7 plants/m^2, 3) applying bioherbicide via two, overlapping passes of an ATV equipped with a boomless, single-nozzle spray system (rate of application of 7.5×10^{12} spore ha^{-1}), 4) mowing again and finally 5) applying bioherbicide two more times through spot sprays via backpack sprayer (Weaver *et al.,* 2016b). Mechanical methods using machines to clear dense kudzu infestations are a good way of increasing the efficiency of (bio)herbicide treatments, but often are not a viable option because of the slopes where kudzu is frequently found and may not be appropriate in natural areas (Miller *et al.,* 2015; Weaver *et al.,* 2016a).

SCALE OF APPLICATION

This method was tested in a private land near Eden Mississippi, USA, using part of the plots (9) used in the experiment, which were 2 m wide and at least 15 m long, totalling an approximate area of 270 m^2 (Weaver *et al.,* 2016b).

EFFECTIVENESS OF THE MEASURE

Neutral.

The continuous pressure applied by this measure on recovering kudzu plants was largely successful in preventing kudzu regrowth during the growing season. The authors report that the overall efficacy of the measure was 91% after one year and 95% after 2 years (Weaver *et al.,* 2016b), but there is no indication of the effectiveness of the measure in suppressing kudzu underground tubers and crowns over time, which is essential to kill the kudzu plants.

EFFORT REQUIRED

This measure was undertaken for 2 years.

RESOURCES REQUIRED

Resources required to undertake this measure involve access to trained staff, required machinery and equipment for mowing and application of bioherbicides, costs for the purchase of bioherbicides and adequate native plants for revegetation.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

This measure promotes a rapid transitioning from non-usable infested areas to productive use; when properly executed, it may also help minimise soil erosion that may result from kudzu removal (Weaver *et al.,* 2016b). On the other hand, as mentioned before, *M. verrucaria* is a fungal pathogen capable of damaging species of economic interest (Garibaldi *et al.,* 2016). Even though *M. verrucaria* is also known to produce mycotoxins that are highly toxic to mammals (Hoagland *et al.,* 2007), it has been found that these can be removed from the fungus spores while retaining the desired virulence (Weaver *et al.,* 2012).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Although less damaging to the environment than the application of chemical herbicides, the measure might face opposition by some stakeholders due to its potential side effects.

LEVEL OF CONFIDENCE*

Established but incomplete.

This integrated measure has only been tested once and, although the study presented is robust and many other studies have shown the bioherbicide potential in controlling kudzu, more field studies are needed to support the results found and to understand if the measure can be effective in controlling underground tubers over time.

* See Appendix

Solarization

MEASURE DESCRIPTION

Soil solarization is a method that can be used to control low growing weed infestations by using polyethylene sheeting to cover the soil and trap solar energy during the weed's growing season, causing solar-enhanced heating of the soil and suppressing the invasive plant (Miller *et al.,* 2015). Polyethylene sheets kill substantial numbers of kudzu crowns and can also be used to knock down kudzu foliage (Newton *et al.,* 2008; http://kokudzu.org/Sheet_Comparison.html). After control of the species, the bare soil is open for reinvasion from the surroundings, unless desirable revegetation is gained (Miller *et al.,* 2015).

Black sheeting is more effective killing kudzu than clear sheeting and the use of UV-resistant sheeting, although adding an extra cost, is more cost-effective, because it extends the life of sheets to more than one growing season. Sheets can be held in place with soil mounds and squares of old carpet (Newton *et al.,* 2008; Miller *et al.,* 2015).

This measure is not cost-effective for the control of large kudzu infestations, but it can be useful as a first treatment in relatively small infested areas (for example followed by physical or chemical control) or in places where chemical control cannot be used, such as along streams or in other sensitive areas (Newton *et al.,* 2008; Miller *et al.,* 2015).

Pueraria montana (Pueraria lobata) © *Schurdl. CC BY-SA 4.0*

SCALE OF APPLICATION

In a study performed in the USA, the plots used for solarization treatments measured 6.1 m by 30.5 m (Newton *et al.,* 2008).

EFFECTIVENESS OF THE MEASURE

Effective.

Soil solarization has been shown to be effective in controlling kudzu from small and/or environmentally sensitive infested areas. Newton *et al.,* (2008) tested different solarization treatments to control kudzu populations, as follows: (i) covering with plastic for the entire growing season, (ii) covering for 1 week and then uncovering for 1 week on an alternating schedule during the growing season, and (iii) covering for 1 week and then uncovering for 4 weeks repeatedly throughout the growing season. Although after the first growing season kudzu root crown mortality was only 42%, 35%, and 24%, respectively, after the second growing season mortality of kudzu root crowns was 97% for all treatments and no visible kudzu growth was detected after the third growing season.

Other studies report resprouting of kudzu after the application of polyethylene sheeting, but in both cases this was only assessed very shortly after the treatment was applied, and no long-term follow up is available (Miller *et al.,* 2015; http://kokudzu.org/Sheet_Comparison.html).

EFFORT REQUIRED

At least 2 years of summer cover are needed to suppress most invasive plants by 90% (Miller *et al.,* 2015). Indeed, Newton *et al.,* (2008) reported that soil solarization provided effective kudzu control if applied for two continuous growing seasons.

Summer is the best season to apply this measure, and its use on wet soils increases control (Miller *et al.,* 2015).

RESOURCES REQUIRED

Miller *et al.,* (2015) report the costs of polyethylene sheeting ranging from $1,500 to $3,500 per acre (1,360-3,166 EUR), although Newton *et al.,* (2008) report lower costs ranging from approximately $1,100 to $5,940 per ha (995-5,374 EUR). In any case, additional resources are required to cover for personnel and transportation to install the sheets in the field.

SIDE EFFECTS

Environmental: Neutral or mixed
Social: Neutral or mixed
Economic: Neutral or mixed

Solarization is a non-selective method, which means that other plants that exist in the infested area will also be killed (Miller *et al.,* 2015). Although solarization can alter soil fertility, it has been shown that interval solarization treatments preserve, or even enhance, soil fertility (Adams *et al.,* 2010).

ACCEPTABILITY TO STAKEHOLDERS

Neutral or mixed.

Solarization may be an attractive solution for some stakeholders to control small kudzu patches using a non-chemical, non-specialised approach (Newton *et al.,* 2008). On the other hand, the environmental side effects of the measure might make it face some opposition.

ADDITIONAL COST INFORMATION

No information available.

LEVEL OF CONFIDENCE*

Established but incomplete.

Solarization has been shown to be a possible method of control of different invasive weeds, including small kudzu-infested patches. However, many more studies performed in kudzu-infested areas are needed.

* See Appendix

Bibliography

Adams, N. E., Mikhailova, E. A., Schlautman, M. A., Bridges, W. C., Newton, C. H., *et al.,* (2010). Effects of Kudzu (*Pueraria montana*) Solarization on the Chemistry of an Upper Piedmont South Carolina Soil. *Soil Science*, 175(2), 61-71.

AGIN (2015). Raccomandazioni dell'AGIN B: Compostaggio, fermentazione e incenerimento di neofite invasive. Versione 2.0. Arbeitsgruppe invasive neobiota (Gruppo di lavoro neobiota invasive). https://extranet.kvu.ch/files/documentdownload/151208130251_Raccomandazione_compostaggio_20nov15.pdf.

Augustin, S., Boonham, N., De Kogel, W. J., Donner, P., Faccoli, M., Lees, D. C., *et al.,* (2012). A review of pest surveillance techniques for detecting quarantine pests in Europe. *Bulletin OEPP EPPO Bulletin*, 42(3), 515-551.

Aurambout, J. P., and Endress, A. G. (2018). A model to simulate the spread and management cost of kudzu at landscape scale. *Ecological Informatics*, 43, 146-156.

Barth, B. (2016). How Kudzu, "The Vine that Ate the South," Put Southern Agriculture on the Skids. Modern Farmer. https://modernfarmer.com/2016/10/kudzu/

Berisford, Y. C., Bush, P. B., and Taylor, J. W. (2006). Leaching and persistence of herbicides for kudzu (*Pueraria montana*) control on pine regeneration sites. *Weed Science*, 54, 391–400.

Bravo M. A. (2008). Data Management Challenges in Regulatory Weed Programs. Proceedings of the Weed Science Society of America, 48, p. 177. http://wssa.net/meeting/meeting-abstracts/

Bravo, M. A. (2009). Evaluation of Kudzu Control Program in Pennsylvania. Proceedings of the Weed Science Society of America, 49, p. 417. http://wssa.net/meeting/meeting-abstracts/

Bravo, M. A., *et al.,* (2009). Pilot Kudzu Eradication Program in Pennsylvania. 62nd Annual Meeting of the North-eastern Weed Science Society, Baltimore Maryland.

Bravo, M. A. *et al.,* (2012a). Lead author of the PROPOSED REVISION NOXIOUS WEED AND RESTRICTED PLANT ACT. An Act relating to noxious weeds and restricted plants; creating a Noxious Weed Control Committee and defining its powers and duties; imposing powers and duties on the Secretary of Agriculture and municipalities; providing penalties; and making a repeal. Last amended: April 7, 1982, P.L. 228, No. 74. PA Dept. of Agric., Harrisburg, PA. *In* 2017 Act 46, Pennsylvania Assembly, Session of 2017, No. 2017- 46. Accessed on April 22, 2019.

Bravo, M. A., and Miller, J. (2010). Kudzu Eradication Program in Pennsylvania. Armel, G. R. (Ed.), Proceedings of the Sixty-fourth Annual Meeting of the North-eastern Weed Science Society, 64, 33. University of Tennessee, Knoxville. https://www.newss.org/proceedings/proceedings_2010.pdf

Bravo, M. A., Zoschg Jr., J., and Bowers, I. (2012b). Federal Noxious Weed Programs in Pennsylvania and Surrounding States. Proceedings of the Weed Science Society of America, 52, p. 403. http://wssaabstracts.com/public/9/proceedings.html

Britton, K. O., Orr, D., and Sun, J. (2002). Kudzu. In: van Driesche, R., *et al.,* 2002, Biological Control of Invasive Plants in the Eastern United States, USDA Forest Service Publication FHTET-2002-04, 413 p. U.S. Department to of Agriculture, Athens, Georgia, USA. https://www.invasive.org/biocontrol/pdf/25Kudzu.pdf

CABI (2019). *Pueraria montana* var. *lobata* (kudzu). [original text by Nick Pasiecznik]. In: Invasive Species Compendium. Wallingford, UK: CAB International. www.cabi.org/isc. Accessed April 23, 2019.

Crable, A. (2007). Kudzu unfurling its fast-growing vines into Lancaster County. Lancaster Online. https://lancasteronline.com/outdoors/kudzu-unfurling-its-fast-growing-vines-into-lancaster-county/image_0f0a0251-c1ae-53be-9347-75506433cd70.html

Egan, A. N., Vatanparast, M., and Cagle, W. (2016). Parsing polyphyletic *Pueraria*: Delimiting distinct evolutionary lineages through phylogeny. *Molecular Phylogenetics and Evolution*, 104, 44–59.

EPPO (2004). EPPO Global Database. First report of *Pueraria montana* var. *lobata* (kudzu) in Italy: addition to the EPPO Alert List.

Esch, M. (2019). Wags and weeds: Invasive plants meet match in detection dogs. The Associated Press.

Farm Journal (1923). Can't Keep Kudzu Down. In: the Farm Journal, 47 (March), p. 69. Wilmer Atkinson Company. Washington Square, Philadelphia.

Follak, S. (2011). Potential distribution and environmental threat of *Pueraria lobata. Central European Journal of Biology*, 6(3), 457-469.

Forseth I. N., and Innis, A. F. (2004). Kudzu (*Pueraria montana*) history, physiology, and ecology combine to make a major ecosystem threat. *Critical Reviews in Plant Sciences*, 23, 401-413.

Frisoli, S., and Crosta, G. (2017). Lotta alle neofite invasive. Taglio del colletto 2017. Caritas Ticino.

Galasso, G., Conti, F., Peruzzi, L., Ardenghi, N. M. G., Banfi, E., Celesti-Grapow, L., and Bandini Mazzanti, M. (2018). An updated checklist of the vascular flora alien to Italy. *Plant Biosystems*, 152(3), 556-592.

Garibaldi, A., Gilardi, G., Franco-Ortega, S., and Gullino, M. L. (2016). First report of leaf spot of spinach (*Spinacia oleracea*) caused by *Myrothecium verrucaria* in Italy. *Plant Disease*, 100(8), 1786-1787.

Geerts, S., Mashele, B. V., Visser, V., and Wilson, J. R. U. (2016). Lack of human-assisted dispersal means *Pueraria montana* var. *lobata* (kudzu vine) could still be eradicated from South Africa. *Biological Invasions*, 18(11), 3119-3126.

Gigon, A.,, Pron, S., and Buholzer, S. (2014). Ecology and distribution of the southeast Asian invasive liana kudzu, *Pueraria lobata* (Fabaceae) in Southern Switzerland. *Bulletin OEPP/EPPO Bulletin*, 44(3), 490-501.

Glendale California Police Department (2019).K-9 Unit: FAQ. Accessed on April 22, 2019. https://www.glendaleca.gov/government/departments/police-department/k9-unit/faq

Harrington T. B., Rader-Dixon, L. T., and Taylor Jr., J. W. (2003). Kudzu (*Pueraria montana*) community responses to herbicides, burning, and high-density loblolly pine. *Weed Science*, 51, 965-974.

Heuzé, V.,, Tran, G., Hassoun, P., Bastianelli, D., and Lebas, F. (2017). Tropical kudzu (*Pueraria phaseoloides*). Feedipedia, a programme by INRA, CIRAD, AFZ and FAO. https://www.feedipedia.org/node/257

Hoagland, R. E., Weaver, M. A., and Boyette, C. D. (2007). *Myrothecium* verrucaria fungus: A bioherbicide and strategies to reduce its non-target risks. *Allelopathy Journal*, 19(1), 179-192.

Illustrated World (1920). Oriental Immigrant from the Plant Kingdom. In: Illustrated World. Volume 34 (September), 279–280.

Klapwijk, M. J., Hopkins, A. J. M., Eriksson, L., Pettersson, M., Schroeder, M., Lindelöw, A., Rönnberg, J., *et al.,* (2016). Reducing the risk of invasive forest pests and pathogens: Combining legislation, targeted management and public awareness. *Ambio*, 45(Suppl 2), 223-234.

Krupnick, G. (2014). Research Scientist Spills the Beans. The Plant Press. A Quarterly Newsletter From The Botany Dept (NMNH) And The U.S. National Herbarium. Volume 17(1). https://nmnh.typepad.com/the_plant_press/2014/02/research-scientist-spills-the-beans.html

Leach C. F. (1921). Perpendicular Pastures. Hoards Dairyman, Volume 61, January 21. p. 8. Follow up letter from John B. Chapman. March 11, 1921. p. 332.

McCullough, D. G., Work, T. T., Cavey, J. F., Liebhold, A. M., and Marshall, D. (2006). Interceptions of nonindigenous plant pests at US ports of entry and border crossings over a 17 period. *Biological Invasions*, 8, 611-630.

Miller, J. H. (1996). Kudzu Eradication and Management. In: Hoots, D., Baidwin, J. (eds.). Kudzu the vine to love or hate. Kodak, TN: Suntop Press, 137-149.

Miller, J. H., Manning, S. T., and Enloe, S. F. (2015). A Management Guide for Invasive Plants in Southern Forests. U.S. Department of Agriculture, Forest Service, General Technical Report SRS–131, 120 pp.

Minogue, P. J., Enloe, S. F., Osiecka, A., and Lauer, D. K. (2011). Comparison of Aminocyclopyrachlor to Common Herbicides for Kudzu (*Pueraria montana*) Management. *Invasive Plant Science and Management*, 4(4), 419-426.

Montagnani, C., Gentili, R., and Citterio, S. (2018). *Pueraria lobata*. In: Bisi F., Montagnani C., Cardarelli E., Manenti R., Trasforini S., Gentili R., Ardenghi N.M.G., Citterio S., Bogliani G., Ficetola F., Rubolini D., Puzzi C., Scelsi F., Rampa A., Rossi E., Mazzamuto M.V., Wauters L.A., Martinoli A. Strategia di azione e degli interventi per il controllo e la gestione delle specie alloctone in Regione Lombardia. http://www.naturachevale.it/wp-content/uploads/2019/02/Pueraria-lobata.pdf.

Morisoli, R., Conedera, M., Moretti, G., Crivelli, S., Soldati, V., Bertossa, M., and Pezzati, G. B. (2018). Stratégie de lutte envers une néophyte envahissante – exemple de la puéraire (*Pueraria lobata*). *Schweizerische Zeitschrift fur Forstwesen*, 169(2), 102-109.

Morse, W. J. (1929). Re Kudzu. Travels in Hokkaido. Letter to Dr. A.J. Pieters. Office of the Forage Crops, USDA. Published in William J. Morse, History Of His Work With Soybeans And Soyfoods (1884-1959) by William Shurtleff and Akiko Aoyagi.

Newton, C. H., Nelson, L. R., DeWalt, S. J., Mikhailova, E. A., Post, C. J., Schlautman, M. A., Cox, S. K., Bridges, W. C., and Hall, K. (2008). Solarization for the control of *Pueraria montana* (kudzu). Weed Research, 48, 394-397.

Taylor, W. M. A. (1929). Circular 89. Kudzu. United States Department of Agriculture Circular. Contributions of the Bureau of Plant Industry. Office of Forage Crop Investigations.

Teodoro-Morrison, T., Diamandis, E. P., Rifai, N., Weetjens, B. J, Pennazza, G., de Boer, N. K., and Bomers, M. K. (2014). Animal Olfactory Detection of Disease: Promises and Pitfalls. *Clinical Chemistry*, 60(12), 1473-1479.

USDA (2016). Combined Control Tactics Remove Kudzu Faster. USDA AgResearch Magazine. https://agresearchmag.ars.usda.gov/2016/jul/kudzu/

Weaver, M. A., Boyette, C. D., and Hoagland, R. E. (2012). Bioherbicidal activity from washed spores of *Myrothecium verrucaria*. *World Journal of Microbiology and Biotechnology*, 28, 1941–1946.

Weaver, M. A., Boyette, C. D., and Hoagland, R. E. (2016a). Management of kudzu by the bioherbicide, *Myrothecium verrucaria*, herbicides and integrated control programmes. *Biocontrol Science and Technology*, 26(1), 136–140.

Weaver, M. A., Boyette, C. D., and Hoagland, R. E. (2016b). Rapid kudzu eradication and switchgrass establishment through herbicide, bioherbicide and integrated programmes. *Biocontrol Science and Technology*, 26(5), 640-650.

Webster, T. M. (2006). Controlling Tropical Spiderwort in the Southeast. USDA, AgResearch Magazine. https://agresearchmag.ars.usda.gov/2006/sep/spider/

van der Maesen, L. J. G. (1985). Revision of the genus *Pueraria* DC with some notes on *Teyleria* Backer (Leguminosae). Agricultural University Wageningen Papers 85-1, 130 p.

Appendix

Level of confidence provides an overall assessment of the confidence that can be applied to the information provided for the measure.

- **Well established:** comprehensive meta-analysis or other synthesis or multiple independent studies that agree. *Note:* a meta-analysis is a statistical method for combining results from different studies which aims to identify patterns among study results, sources of disagreement among those results, or other relationships that may come to light in the context of multiple studies.
- **Established but incomplete:** general agreement although only a limited number of studies exist but no comprehensive synthesis and/or the studies that exist imprecisely address the question.
- **Unresolved:** multiple independent studies exist but conclusions do not agree.
- **Inconclusive:** limited evidence, recognising major knowledge gaps

Your feedback is important. Any comments that could help improve this document can be sent to ENV-IAS@ec.europa.eu